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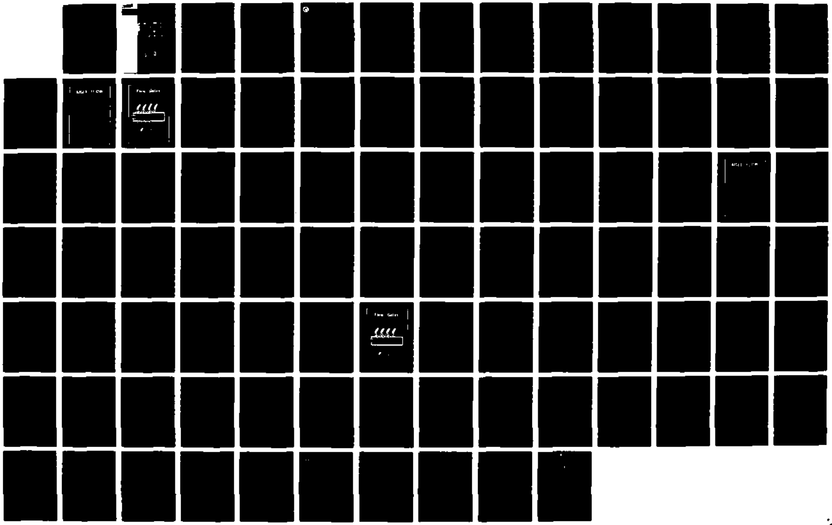

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DIRECT COMMISSARY SUPPORT SYSTEM (DICOMSS) DESIGN SIMULATION

DEPARTMENT OF DEFENSE

DEFENSE LOGISTICS AGENCY

Cameron Station,
Alexandria, Virginia 22304 6100

Operations Research and Economic Analysis Office

December 1986

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A simulation analysis was performed on the Defense Mechanization Support Office (DMECSO) design for an automated material handling system for the Direct Commissary Support System (DICOMSS) at the Defense Depot Mechanicsburg, Pennsylvania (DDMP). A pick-to-belt system, coupled with a bar code sortation system, was the main enhancement to the picking and palletizing area. An automated guided vehicle (AGV) system was employed to carry pallets from receiving to storage. Several significant recommendations were made concerning the design. The AGV system was not cost effective. A second sortation belt was needed to alleviate congestion and to provide redundancy. In addition, numbers of specific resources (e.g., number of forklifts, turret trucks, etc.) to procure was also provided.

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DIRECT COMMISSARY SUPPORT SYSTEM

(DICOMSS) DESIGN SIMULATION

December 1986

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FOREWORD

This report details the results of a simulation of the proposed materials handling enhancements for the Direct Commissary Support System (DICOMSS) warehousing operation at Defense Depot Mechanicsburg, Pennsylvania. The baseline design, proposed by the Depot Mechanization Support Office, employs a pick-to-belt strategy for stock selection, expanded rack storage capability, an Automated Guided Vehicle system, and many enhancements to both the receiving and the packing/shipping operation.

Study results indicate that additional capability will be needed in the final sortation system to adequately process the forecasted workload. The study results also indicate that the Automated Guided Vehicle system, as designed, is not cost effective. Other results indicate that additional packing stations may be required to process projected workload levels.

for ROGER C. ROY
Acting Assistant Director
Policy and Plans

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EXECUTIVE SUMMARY

The Direct Commissary Support System (DICOMSS) warehousing operation at Defense Depot Mechanicsburg, Pennsylvania, is experiencing significant growth in workload while operating in very constrained building space and with little mechanization. The Depot Mechanization Support Office (DMECSO) was tasked with designing a system to handle anticipated increases in workload within the confines of the present building space. The DMECSO baseline design incorporates a pick-to-belt system for stock selection, an Automated Guided Vehicle (AGV) system for assistance in both receiving and full pallet selections, and other automated enhancements to enable the system to complete anticipated throughput requirements in one shift.

The DLA Operations Research and Economic Analysis Management Support Office (DORO) was tasked to perform a computer simulation of the DMECSO design to test for system feasibility and determine if the system could function efficiently with the projected throughput rates. This report details the results of that study and provides recommendations to ease potential system bottlenecks and improve system efficiency.

Simulation results indicate that the AGV system, as designed, may not be a good investment. Results indicate that one additional forklift in the receiving area provides equivalent efficiency at significantly reduced costs. Due to excessive stowing requirements, the study also indicates that an additional man-up turret truck (aisle stowage device) will be required to accomplish the workload in a one-shift operation.

In the packing/consolidation area, simulation results indicate that the baseline system cannot process the workload in one shift and that significant bottlenecks occur in the final sortation loop area. Two alternatives were simulated to alleviate the bottleneck: 1) speeding the final belt from 200 to 285 feet per minute and 2) adding a second parallel sortation belt. While both alternatives showed marked improvements over the baseline design, study results indicate that adding a second sortation belt is the better alternative.

Other recommendations include the addition of packing stations to increase throughput potential and software changes to the Seavan Planner to allow for balancing of picking workload among the aisles. The Seavan Planner in its current form will only group workload by cube constraints and makes no attempt to balance workload among the aisles, thus causing potential congestion and inefficiencies.

I. INTRODUCTION

A. DICOMSS Mission. The Direct Commissary Support System (DICOMSS) provides material support to overseas commissary stores for nonperishable and semiperishable grocery items. Defense Personnel Support Center (DPSC) processes requisitions, aggregates orders, and contracts for material requested by these stores. The DICOMSS warehousing center, located at Defense Depot Mechanicsburg, Pennsylvania (DDMP), serves as a break-bulk point for these items destined for over 70 commissary stores in Europe and the Caribbean. All material handled by this warehousing system is "presold" in that no operating levels are maintained and everything received has already been requisitioned. Material is received, inspected, consolidated, and shipped in seavans to its ultimate destination. Approximately 4,000 different items are stored in the DICOMSS warehouse at any one time.

B. Present Warehousing System Design and Problem Areas

The current DICOMSS warehousing system is very labor and forklift intensive. The system employs a Seavan Planner which is a software system designed to batch requisitions for each commissary store of sufficient size to fill a seavan. Stock selectors are dispatched on forklifts with groups of "pick tickets," generated by the Seavan Planner, to build pallets of material. Each pallet is destined for a single commissary. Thus, during a day a particular pick facing may be visited many times. As soon a. a pallet is built it is driven to a staging area where it is stretch wrapped and moved onto a seavan. During peak workload times, forklift traffic is extremely heavy and, consequently, working conditions are potentially hazardous.

Throughput requirements are expected to increase significantly during the next several years. The present system is already operating at capacity in terms of usable storage space and selection/receiving capability. The incredible volume of forklift traffic has provided an unsafe environment both in terms of collision risks and associated exhaust fumes.

C. DMECSO Proposed Solution

The Defense Mechanization Support Office (DMECSO) was tasked with finding solutions to the system's current problems and providing for the anticipated growth in activity. Improved storage aids are planned to maximize use of available space and allow for better use of higher areas. A pick-to-belt concept is being considered which would eliminate the need for forklifts to be used in the picking process. While at a pick facing, the stock selector may be picking for many different commissary stores. Stock selectors pick the material, afix bar-code labels, and place the cases on conveyor belts which transport them to a packing lane sortation loop. Cases pass a bar-code scanner which directs them to one of six packing stations where they are palletized and put into seavans.

Enhancements in the receiving area are also being planned which include the use of an Automated Guided Vehicle (AGV) system to transport full pallet material across the two building complex to bulk locations. The AGV system is incorporated into the picking process to handle full pallet selections from bulk locations.

D. Objectives and Scope of Study. The Defense Logistics Agency Operations Research and Economic Analysis Management Support Office (DORO) was tasked to perform a computer simulation of the DMECSO proposed design. Of critical interest was whether the enhancements to the system would meet the anticipated throughput requirements. The simulation was limited to the enhancements made to DICOMSS warehouse space in Buildings 506 and 507. The functions of unloading, receiving, inspection, stowage, consolidation, and loading were modeled. The model utilized workload and throughput projections provided by DMECSO.

E. Report Structure. The purpose of this report is to discuss the critical findings of the study and to detail the specific conclusions and recommendations. A detailed technical report is included as Appendix A to provide in-depth documentation of assumptions, modeling techniques, data development, decision logic, sensitivity analysis, and a more complete discussion of results.

II. METHODOLOGY OVERVIEW

The system was simulated as two separate modules, receiving and pick-to-belt. The break between these two sections was selected because of their very limited operational interface. Also, the current system accomplishes these two functions on different shifts; therefore, enhancements would most likely be handled with a similar approach. The only potentially shared resource between the two systems is the AGV system which could be used for performing bulk picks. This interface was represented by statistical distributions. This allowed the model to run more efficiently and provided modeling flexibility.

The baseline scenario in both modules was based upon DMECSO projections of DICOMSS workload in the 1990 timeframe. This scenario included the proposed mechanization of Buildings 506 and 507, the DMECSO plans for enhanced storage aids, and the expected throughput requirements in that timeframe. As a result of early simulation results, alternative scenarios were modeled in both areas in an attempt to ease bottlenecks and to improve system efficiency.

III. DATA DEVELOPMENT OVERVIEW

The data development phase involved several meetings with DMECSO personnel, a trip to a similar pick-to-belt system operating in the private sector, background reading into conveyor belt and AGV system operation and capabilities, and formal requests for data from DMECSO. During this process, a close interface with DMECSO personnel was maintained to clarify

data inputs and explain system operation. An interim briefing prompted further clarification and redirected modeling efforts in several areas. A copy of the formal data request and the DMECSO reply is enclosed as Appendix B.

The specifics of the data collection task were organized in terms of the proposed physical design, resource capabilities and requirements, and other throughput requirements. These data areas are discussed in detail in the Data Development section of Appendix A.

IV. MODEL LOGIC FLOW

A. Receiving/AGV Module

The receiving module incorporated logic to handle new receipts, pallets received from Building 405, and the AGV system. The module dealt with four different types of pallets. The first two types were bin and bulk replenishment pallets from the truck receiving portion of the module. The last two types were full pallet (bulk) picks and manually built pallets from the nonmechanized portion of DICOMSS (Building 405). Both of these types were handled using the AGV system logic.

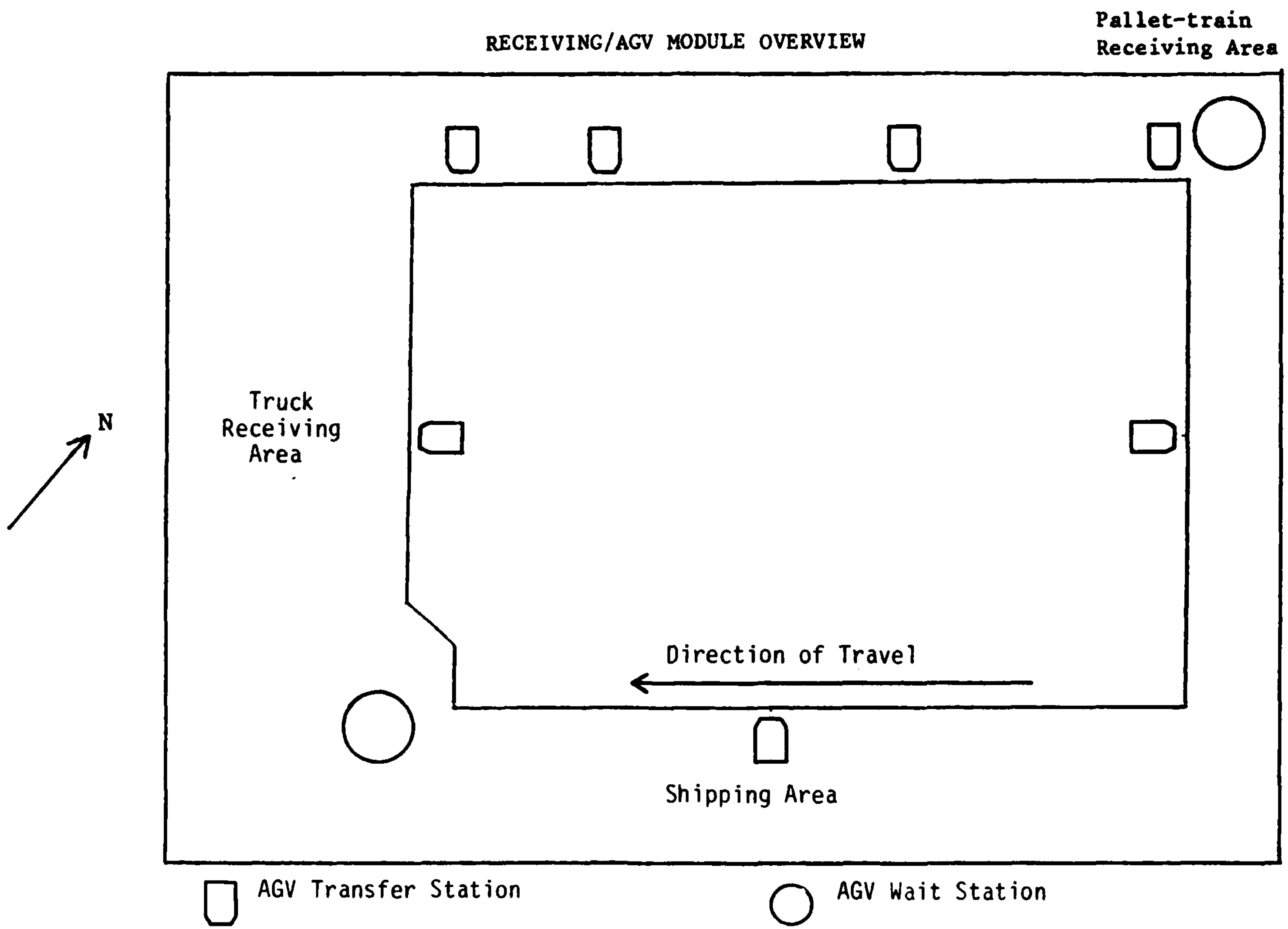
Figure 1 is a representation of the different functional areas included in this module. The majority of the pallets processed in the receiving module are pallets unloaded from trucks arriving at random throughout the day. Material was unloaded from a truck, inspected by the forklift operator for obvious damage and quantity discrepancies, checked by the Veterinary (VET) inspectors, and sent to either bin or bulk replenishment areas.

Bin replenishment pallets were sent by forklift to the pallet racks and carton flow racks which fed the pick-to-belt module. These pallets were first transferred to one of eight aisle staging areas within the two building mechanized complex. The staged pallets waited for a man-up turret truck to accomplish the actual stow. The process entailed loading the pallet from the aisle staging area, locating the particular destination within the aisle, traveling to the destination, and placing the pallet (cartons) into the pallet rack (carton racks).

Handling of bulk replenishment pallets depended on the pallet destination within the bulk storage areas. Pallets destined for bulk storage areas on the truck receiving side of the mechanized complex were taken to their destination directly by a receiving area forklift. Pallets destined for bulk storage areas on the opposite half of the complex were transferred across the building on an AGV and stowed using forklifts from the offload area (see Figure 1). Specifically, these pallets waited for an available receiving area forklift, were loaded on the forklift, and traveled to the least utilized receiving area AGV station. The forklift operator transferred the pallet to the AGV station, keyed in the destination station, and returned to the receiving area to process other pallets. After the pallet was transferred across the building on an AGV, a forklift from the pallet-train receiving area offloaded it from the AGV station, traveled to the bulk storage destination, and accomplished the stow.

Figure 1

RECEIVING/AGV MODULE OVERVIEW



Bulk pick pallets from within the mechanized complex were located, loaded onto a forklift, transferred to the nearest AGV station, and sent to the shipping area. A single dedicated bulk picking forklift accomplished all the picks. Once the picks were completed, the forklift was transferred to the receiving area to help with truck offloading and replenishment actions.

The final type of pallets modeled were those transferred into the mechanized complex from the nonmechanized portion of DICOMSS (Building 405). These pallets came into the system in the north corner of the building (see Figure 1). They arrived on pallet trains and were unloaded by forklift, taken to an AGV station, loaded onto a vehicle, and transferred to the shipping area.

B. Pick-to-Belt Module

Case selections were generated after delays based upon stock selector travel time, bar-code application time, and various other factors affecting worker speed. Stock selection on the ground floor level was accomplished by walking pickers while upper level selections were made by pickers riding in mechanized carts. Once cases entered the conveyor system, they were tracked through various merge points and accumulator belts. The baseline system design called for all cases to merge into one master sortation belt loop where bar-codes were scanned and cases were sent to appropriate packing lanes. Figure 2 outlines the basic configuration of the conveyor system within the aisles of the mechanized complex.

Availability of space on the belts was determined not only by the number and location of cases on the belts but also by whether or not the belt was moving or blocked. Open and shut conditions were placed on the flow of cases over these belts by the use of simulated gates. When an aisle gate was closed, cases were denied access to that conveyor belt. This situation would occur in the real system if the accumulation belts were filled causing a shutdown of the belt to which the stock selector was picking. Similar gates were also used to model the actions of a system monitor at the sortation loop. The system monitor opened and closed these gates based upon given congestion conditions. After traversing the sortation area, cases were sent to one of six packing stations. Cases were then batched into pallets, covered with stretch wrap, and sent by forklift into the seavan. Figure 3 is a representation of the final sortation loop and associated flow gates.

C. Model Verification

Flow statistics were collected at various positions in the model to verify direction and timing of movements. Extensive logic checks and test runs were made to help verify the model. Interim results and model design were reviewed with DMECSO for accuracy, completeness, realism, and expert opinion. Sensitivity analyses were performed on critical modeling points to monitor realism.

Figure 2

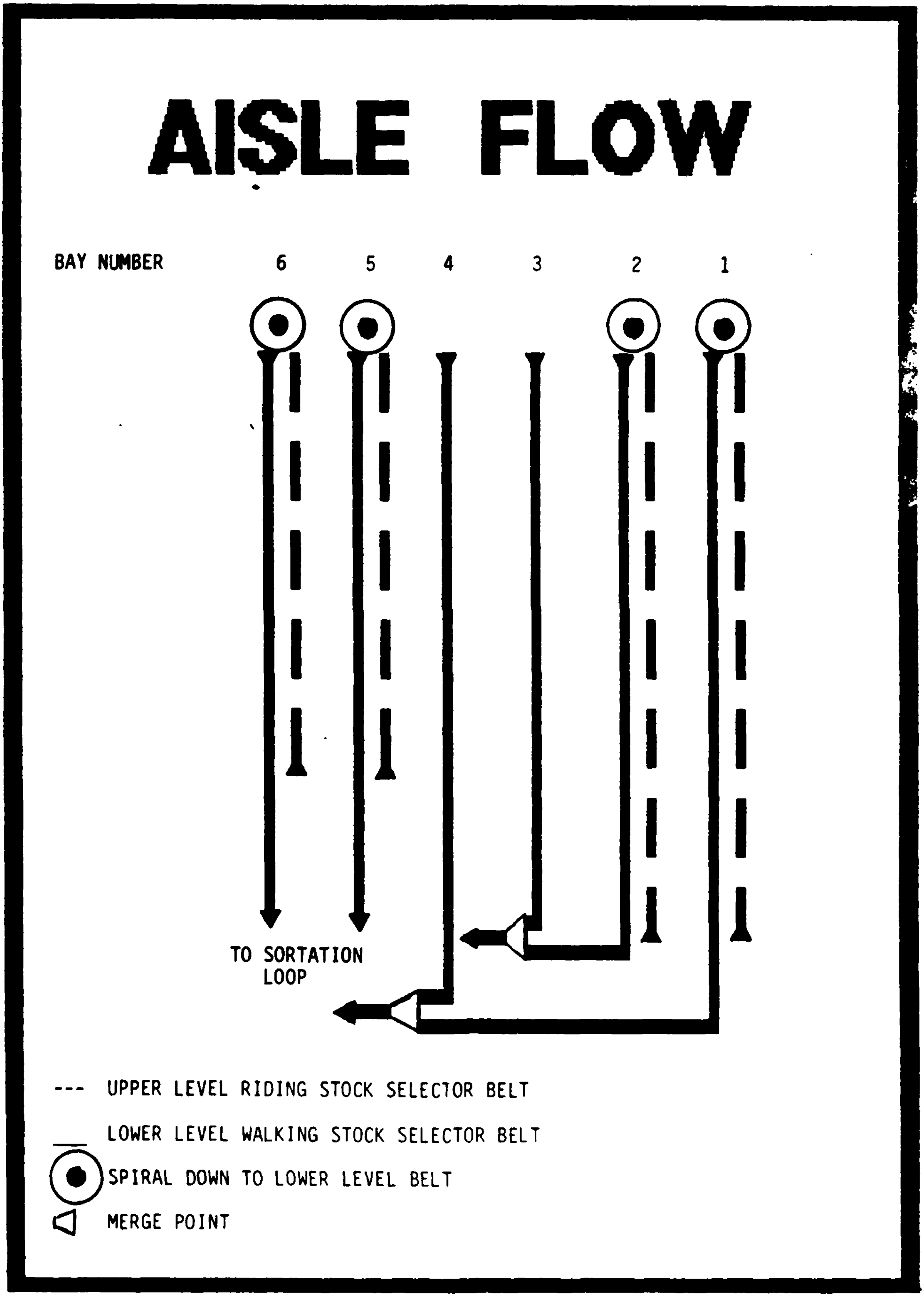
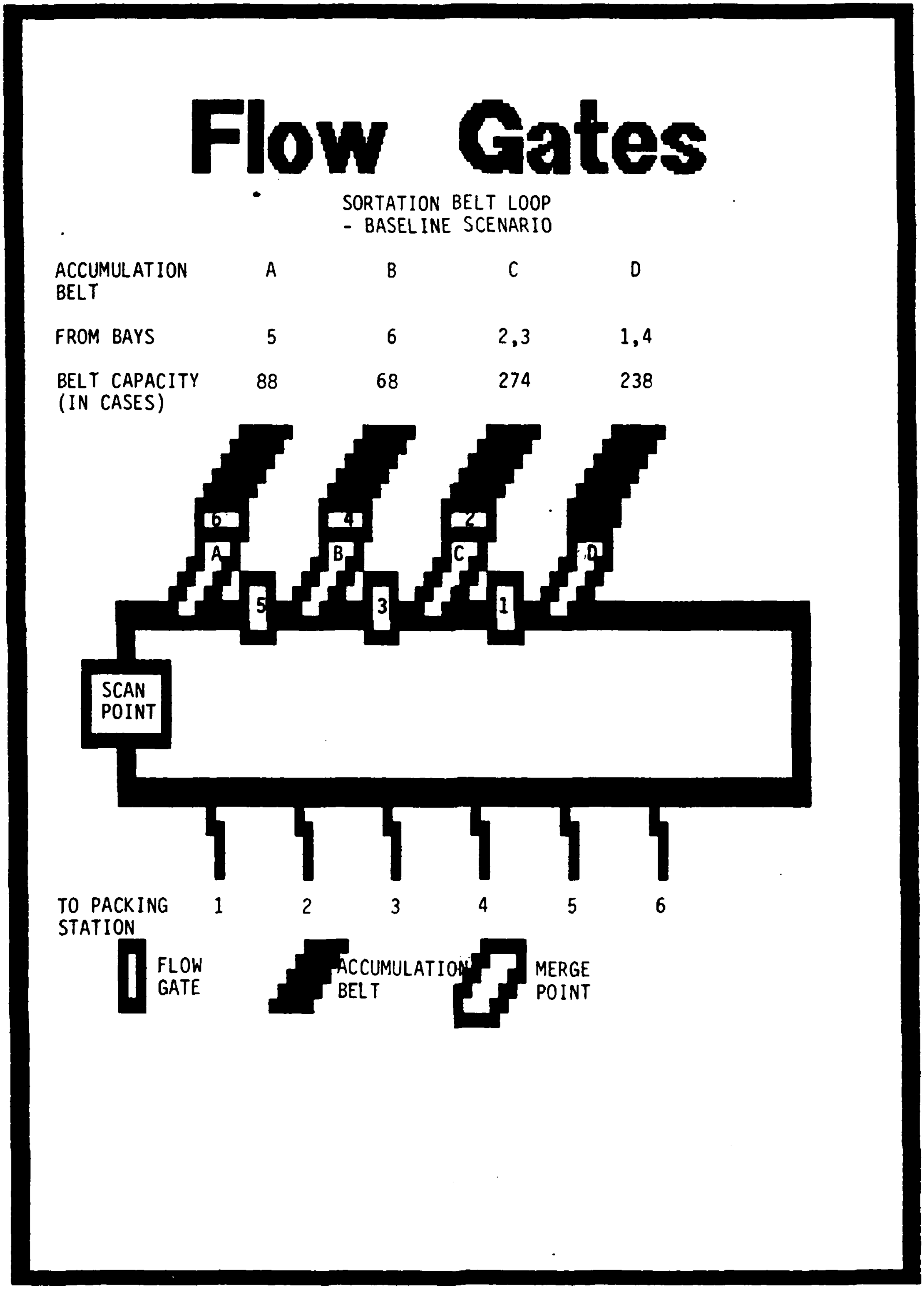

AISLE FLOW
BAY NUMBER
6
5
4
3
2
1
TO SORTATION LOOP
--- UPPER LEVEL RIDING STOCK SELECTOR BELT
LOWER LEVEL WALKING STOCK SELECTOR BELT
SPIRAL DOWN TO LOWER LEVEL BELT
MERGE POINT

Figure 3


Flow Gates
SORTATION BELT LOOP
- BASELINE SCENARIO
ACCUMULATION BELT
A
B
C
D
FROM BAYS
5
6
2,3
1,4
BELT CAPACITY (IN CASES)
88
68
274
238
6
4
2
A
B
C
D
5
3
1
SCAN POINT
TO PACKING STATION
1
2
3
4
5
6
FLOW GATE
ACCUMULATION BELT
MERGE POINT

Validation involves the comparison of model results to real world results. Since the DMECSO design is not yet operational and no other real world system is similar enough to compare results, this type of comparison was impossible.

V. MODEL RESULTS AND ANALYSIS

A. Receiving/AGV Module

1. Overview. The presentation and analysis of the simulation results is divided into four areas. In the first area, observations are made concerning the AGV system design. These observations were the result of the model building process and affect the model results which follow. The first scenario covers the DMECSO design including the AGV system. The second scenario models the system without an AGV system. In this scenario forklifts handled all pallet movement requirements. The last two sections analyze input sensitivity analysis for both scenarios.

2. Initial Design Assessment

The direction of AGV travel was initially specified as counter-clockwise in the design blueprints. However, AGV movement requirements are minimized if the direction of travel is clockwise. Building 405 pallets going to the shipping area and bulk transfer pallets going across the building travel shorter distances with a clockwise rotation. The only other type of pallet movement on the AGV system are bulk pallet picks going to the shipping area. For these pallets, AGV travel distances are equal with either a clockwise or a counter-clockwise rotation. Therefore, the AGV system was modeled with a clockwise direction of travel.

AGV station design is the second recommended change from the original specifications. The original design had the onload portion of the station situated before the offload portion of the station. In this design, a vehicle which offloads a pallet must leave the station area. In terms of response time to pallet movement requirements, it is better to have the offload occur before the onload in the station design. With this sequencing, an AGV which offloads a pallet can simply move over to the onload portion of the station and wait for pallets coming into the station.

3. Initial Resourcing Analysis

The first set of model results was generated to verify that the number of each resource was adequate to handle the baseline receiving workload requirements. Of the receiving resources, the number of turret trucks, VET inspectors, pallet-train receiving area forklifts, truck receiving forklifts, and AGVs were changed from the original specifications.

Results of this part of the analysis indicate that an additional man-up turret truck would be necessary to accomplish the anticipated workload in a one shift environment. Initial resourcing results also showed extensive pallet queueing in the receiving staging areas. Because of this constraint, the number of VET inspectors required was increased to 18. The third resource type altered from original specifications was the number of pallet-train receiving area forklifts. Verification runs showed two forklifts (instead of three) could handle the workload.

Truck receiving forklifts and the number of AGVs were the last two resources altered as the result of model output analysis. Because of the interaction among the number of these two resource types, a separate analysis based upon an experimental design was accomplished. The results of this analysis are presented below.

4. Resource Sizing

a. With an AGV System

An experimental design was also used to test resourcing requirements. In the design, the number of receiving area forklifts was varied between six and twelve and the number of AGVs was varied between eight and twelve. The results indicated that more receiving area forklifts were needed and that fifteen AGVs were significantly more than necessary. Nine receiving area forklifts, eight AGVs, and two pallet-train receiving area forklifts were sufficient to complete the workload in one shift.

The use of at least eight AGVs is recommended based on station queueing. AGV stations have an eight pallet capacity on the on/offload belts. Less than eight AGVs results in the receiving area AGV station onload belts being filled up. As a result, forklifts could not load additional pallets onto the stations at certain times during the simulated day.

b. Without an AGV System

The second scenario modeled the operation without an AGV system. In this case, forklifts handled all pallet movement requirements within the mechanized complex. An experimental design was again used to determine the mix of resources needed to accomplish the daily workload. Receiving area forklifts were varied between six and twelve and pallet-train receiving area forklifts were varied between one and three.

The number of pallet-train receiving area forklifts which are required remains at two. While the analysis of the system with AGVs indicates that one forklift might potentially handle the workload, the utilization of these two forklifts increases slightly so that one forklift could not handle the workload.

The addition of a single receiving area forklift gives system performance similar to that obtained with an AGV system. Normally, the impact of an automated system like the AGV system in the DMECSO design would be very positive. However, several factors limit the effectiveness of the DICOMSS AGV system.

The main factor limiting the AGV system effectiveness is the time it takes forklifts to interface with the system. The AGV system does not reduce the number of pallets which must be handled by forklifts. Each pallet must still get to the AGV station by forklift, be loaded onto the station by forklift, and be offloaded at the destination station by forklift. This interface time is significant when compared to the forklift travel time savings which are the main benefit of the AGV system.

A second factor limiting the AGV system effectiveness is the time difference between accomplishing a task by forklift as opposed to using the AGV system. For instance, a pallet movement from the Building 405 receiving area to the shipping area takes about 200 seconds by forklift. The same pallet movement takes about 490 seconds on the AGV system.

A final limiting factor is the travel distances of the DICOMSS pallet movement requirements. These range from 300 feet to about 1000 feet. For these movements, the higher speed of forklifts combined with the forklift interface time required with an AGV system tend to offset AGV system benefits.

5. Input Sensitivity Analysis

Given the results of the resource sizing, the purpose of the input sensitivity analysis was to determine how variations in workload would affect system performance. For this analysis, input workload was varied up and down by 25 percent of the original specifications.

Overall system performance is dependent on the completion times for tasks such as truck receiving, bulk picking, and bulk pallet transfers from Building 405. The basic performance measurement is time to complete all receiving functions. These completion times are given in Table 1 for both scenarios.

Table 1

Task Completion Times (in hours)
Workload Variability ± 25%

Task	With AGV System Min	With AGV System Max	Without AGV System Min	Without AGV System Max
Trucks unloaded	5.2	9.1	5.2	9.1
Bulk picks complete	4.2	7.3	5.4	9.1
405 pallets transfered	5.7	10.2	5.6	10.3
Bin Replenishment	6.2	10.2	6.3	10.2
Bulk Replenishment	5.9	9.9	5.8	10.0
All Receiving Tasks	6.5	10.4	6.2	10.5

Expected task completion times are very similar under the two alternative scenarios. The only significant difference between the two scenarios is in the expected time of completion for bulk picks. This time is from 1.2 to 1.8 hours longer in the scenario without an AGV system. The reason for the extended time is the increased workload on the bulk picking forklift as a result of not having the AGV system.

Resource utilization is given in Table 2. The values represent the percent of available resources which were busy (on average) during the time the resource was active. The only significant difference between the two alternatives is in the utilization of pallet-train receiving area forklifts.

Table 2

Resource Utilization

Resource	With AGV System Min	With AGV System Max	Without AGV System Min	Without AGV System Max
Receiving forklifts	66%	69%	64%	66%
Pallet-train rec. area forklifts	34%	46%	54%	55%
Man-up turret trucks	78%	83%	80%	82%
VET inspectors	94%	96%	94%	97%

B. Pick-to-Belt Module Results and Analysis

1. Pick Size Analysis. Essential to achieving throughput goals is the number of seavans which must be loaded each day. The workload goal for the pick-to-belt system is 40,000 cases per day with another 10,000 cases per day coming from other bulk and nonmechanized areas. Given the facts that a seavan can hold about 36 pallets of material, an average pallet can hold 22 cases, and there are a maximum of six seavans to be packed on any one pick cycle, an average pick cycle case drop can be

expected to be about 4,750 cases. It is also true that a significant portion of these cases are coming in full pallet quantities from Building 405 and bulk picks from elsewhere in the two-building mechanized warehouse. This brings the expected number of cases per pick cycle down to approximately 4,300 cases. Therefore achieving 40,000 cases per day through the pick-to-belt system may require 9 or 10 pick cycles each day. The only option in decreasing the number of pick cyles would be to increase the number of packing stations and consequently, the number of seavans packed during a given cycle.

2. Baseline Scenario Simulation Results

In all scenarios tested, pick cycle sizes of 4,300, 6,450, and 8,600 cases were generated to simulate 60, 90, and 120 minutes of stock selection. These sizes were selected based upon considerations discussed above in pick cycle analysis. Table 3 shows how pick cycle completion time varies over these various cycle sizes. As can be seen from the data, considerable time is wrapped up in s stem flow rather than the actual picking process.

Unproductive time for stock selectors is considered to be a way of measuring overall system effectiveness. This unproductive time is defined to be the difference between the actual pick cycle completion time and the pick cycle and the time the stock selectors could have finished picking given that they experienced no delay from the system.

Delays can come from several different areas. First of all, delays can result from lower level walking selectors sharing some of the capacity of their belts with cases coming from the riding selectors above. Given that no other delays occur in the system, these delays are insignificant. Other potential delays include backups at merge points ahead of the selectors which can cause belt shut downs. Depending on the severity of these queue buildups, this can be a very significant amount of time. Lastly, delays include the time it takes the system to clear once the final case has been selected. Table 4 shows the total magnitude of these delays for all stock selectors.

Another measure of system performance is the status of the flow gates which can give a good indication of potential choke points. Table 5 gives a breakdown of the percentage of time flow gates were closed during the simulations. These data indicate significant congestion at the final sortation loop merge points which at some point in each of the simulation runs inhibited the ability of some stock selectors to function.

Table 6 details resource utilization for packers and forklifts/operators. These data include the time waiting for the first cases to travel to the packing lanes. Even considering this fact, excess capacity clearly exists in both resource areas. By speeding the flow of material to the packing lanes, some increased resource utilization can be expected.

Table 3

Pick Cycle Completion Time Statistics
Baseline Scenario
(Times in Hours)

	Pick Cycle Size 4300 Cases	6450 Cases	8600 Cases
Average Value	1.52	2.20	2.81
STD	0.04	0.02	0.04
95% Conf. Interval			
Low	1.45	2.15	2.73
High	1.60	2.24	2.90

Table 4

Aggregate Stock Selector Unproductive Time
Baseline Scenario
(Times in Hours)

	Pick Cycle Size 4300 Cases	6450 Cases	8600 Cases
Average Value	4.64	6.67	7.77
STD	0.36	0.24	0.50
95% Conf. Interval			
Low	3.92	6.20	6.79
High	5.36	7.13	8.74

Table 5

Flow Gate Statistics
Baseline Scenario
(Percentage of Time Flow Gates Open)

Pick Size	Stock Selection Conveyor Belt (% of Time Conveyer Belts Moving) Aisle 1	Aisle 2	Aisle 3	Aisle 4	Aisle 5	Aisle 6
4300 Cases	94.8%	86.7%	89.2%	92.6%	100.0%	97.1%
6450 Cases	86.5%	73.3%	76.7%	89.7%	100.0%	95.7%
8600 Cases	76.8%	65.4%	72.1%	85.0%	100.0%	95.2%

Note 1 : Aisle Number is Equivalent to Bay Number
Note 2 : See Figure 2 for Corresponding Aisle Number

Pick Size	Sortation Belt / Flow Monitor (% of Time Sortation Belt Gate Open) Gate 1	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6
4300 Cases	77.5%	83.3%	95.3%	60.9%	100.0%	56.0%
6450 Cases	76.8%	76.9%	91.3%	53.7%	100.0%	45.1%
8600 Cases	76.1%	77.0%	90.1%	53.2%	100.0%	43.3%

Note 3: See Figure 3 for Corresponding Sortation Belt Flow Gates

Table 6

Resource Utilization Statistics
Baseline Scenario
(% of Cycle Time Busy)

Packer Utilization	4300 Cases	6450 Cases	8600 Cases
Average Value	58.1%	60.7%	63.0%
STD	1.4%	0.8%	1.1%
95% Conf. Interval			
Low	55.3%	59.0%	60.8%
High	61.0%	62.3%	65.2%

Forklift Utilization	4300 Cases	6450 Cases	8600 Cases
Average Value	24.8%	24.8%	25.6%
STD	0.4%	0.2%	0.6%
95% Conf. Interval			
Low	24.0%	24.4%	24.9%
High	25.5%	25.2%	26.9%

3. Potential Choke Points

The major choke points in the baseline scenario appear to be the merges to the main sortation loop. When congestion occurs here, the model shows gradual buildups in the trailing accumulation belts which eventually backs up to some aisles halting the stock selection process for a time. This is the major problem in the baseline design. This bottleneck prevents efficient flow to the packing stations and results in unproductive time for the packers.

The underlying problem can best be explained by considering the window of time each case takes to pass through a merge point. As discussed before, one hardware limitation is that the merge points and the scanner require fixed time (space) delays for cases as they pass. Obviously, since this is fixed, the space allocated for each case must be at least as big as the largest case or else jamming will occur. The scanner, according to the specifications, requires at least a distance between cases of ten inches. Accordingly, a window of three feet of belt space must be allotted to each passing case. At a speed of 200 feet per minute, each case will seize the merge point for 0.9 seconds. The specifications call for at least two cases passing the scan point every second which is an impossibility given the belt speed and the space required per case. In order to meet the standard of two cases each second, the final sortation belt would have to travel at 360 feet per minute. Even if the belt could physically move that fast, it is doubtful that the diverters to the packing stations could function properly at that speed.

4. Effects of Deviations in Workload Among Aisles

The Seavan Planner, which in the current system generates pick batches, is intended to be utilized in the proposed DMECSO design. In its current form, batches of picks are released based upon cube and weight constraints. No attempt is made by the Seavan Planner to balance workload among differing aisles. For this reason, deviation in workload among aisles was tested in the pick-to-belt module.

The number of locations (pick facings) varied by aisle. Two of the four high bay areas had one third of their capacity deleted to allow for accumulation and sortation belt space. Therefore, scenarios were modeled which varied the number of picks on an aisle by the number of available locations to pick from.

Detailed sensitivity analyses of these variations in workload are found in Appendix A. Unfortunately, the excessive congestion experienced at merge points tends to mask the magnitude of the effects of the deviation in aisle workload in terms of cycle completion time. The implication of this is that the selection rate becomes less important when the case will have to wait in line anyway. Differences in best case stock selector completion times of over 1.4 hours were observed in some scenarios.

5. Effects of Speeding the Sortation Belt

Based upon data shown in an interim project briefing, DMECSO requested that the model be tested with a faster sortation belt. In this scenario, the sortation belt speed was increased from 200 to 285 feet per minute. This was done to help alleviate congestion at the merge points and to speed the flow of material to the packing stations. Since excess capacity existed in the packing area, this appeared to be a logical enhancement to the design. One major concern with this enhancement was the ability of the diverters to the packing lanes to handle the increased speed. For modeling purposes, it was assumed that the diverters could keep up with the increased sortation belt speed and that the three foot window of space seized by a case on the sortation belt would be sufficient.

Vast improvements were experienced in overall system performance. Packer capacity was exceeded somewhat at different points in the model causing cases to balk from the packing lanes and circle around the sortation belt. This balking effect is not necessarily bad from a system standpoint because it ensures that packers are more fully utilized, provided that there is adequate space for the overflow on the sortation belt.

6. Effects of Adding a Second Sortation Belt

Because of the excessive queueing problems associated with the baseline scenario merge points, a scenario which added a second sortation belt was modeled. With the addition of the second sortation belt, the number of merge points was decreased and the flow of material to the packing stations was significantly increased.

Improvements in system performance were impressive. As in the previous scenario with a faster belt speed for the sortation loop, balking occurred at the packing lanes which helped ensure increased utilization of resources. Unlike the previous scenarios, the need for a flow monitor was eliminated because very little queueing occurred at merge points, and accumulation belts never exceeded their capacities. Specific system performance data are shown in Tables 17, 18, and 19 of Appendix A.

This two belt scenario also added a very important benefit in that it allowed redundancy in the critical choke point area. A sortation belt malfunction in the previous scenarios implied complete system shut down until the problem was corrected. A second sortation belt allows the system to continue functioning, although at a slower pace, and could significantly reduce the consequences of such a failure. A second sortation belt could lessen the problems associated with the increased speed on diverters and scanners mentioned in the previous section. Provided enough physical space exists in the complex, this appears to be the best alternative.

VI. CONCLUSIONS AND RECOMMENDATIONS

The high costs and limited benefits of the proposed AGV system indicate that it should be reconsidered. The AGV system does not eliminate the need for forklifts as previously suspected but merely redefines their role and increases the number of times they must handle material. Total time to stow a receipt actually increases with an AGV system due to the amount of time associated with getting the pallet to the appropriate AGV station, loading, keying in a destination, traveling to the next station, offloading, and traveling by forklift to the ultimate destination. The AGV system is not only costly and inefficient but also takes up a great deal of floor space which might better be used for storage aids.

Simulation results also indicate that a realignment of certain resources is necessary to achieve anticipated receiving throughput requirements. Ten forklifts are needed in the receiving area (assuming no AGV system). An additional man-up turret truck will be required to complete the workload in a one-shift receiving operation. A total of 18 VET inspectors will be needed to handle expected receipt workload.

In the pick-to-belt area some marked improvements can be made to enhance system performance. First and foremost, steps should be taken to increase the flow of material to the packing stations to take advantage of the excess capacity and alleviate congestion at merge points. This can be accomplished by either speeding the sortation belt or adding a second one. Adding a second sortation belt seems to be the more flexible solution and a better way to relieve congestion and adds redundancy to the design in the most critical choke point area.

One other limiting factor in system throughput is the number of packing stations. As mentioned earlier in the analysis, six packing stations imply an average case drop of about 4,700. A significant portion of these cases are not coming from the pick-to-belt system but from full pallet picks and nonmechanized picks from Building 405. Simulation results also indicate some efficiency increases associated with longer pick cycles in that stock selectors spend less time traveling and more time at the actual pick facing. The net effect is that six packing stations force more pick cycles of shorter size which may not be optimal for the system. More packing stations could increase throughput potential and add some important redundancy to the system. Further simulation in this area may be warranted.

Balanced workload is critical to system performance. Given that bottlenecks at the sortation loop are alleviated by one of the above recommendations, the next potential system inefficiency is the difference in stock selection completion times caused by unbalanced workload. Significant changes will have to be made to the current form of the seavan planning function in order to accommodate this requirement.

The following items are specific recommendations based upon model results:

1. The AGV system be eliminated from the design and that an extra forklift be added to the receiving area to handle the associated increase in workload.

2. In the event that the AGV system is kept:

a. The direction of AGV path be reversed to clockwise.

b. Onload and offload belts at each station be reversed to offload first and onload second.

c. A queueing potential of at least one AGV per station should be incorporated in the design. Simulation results indicate a significant balking problem for AGVs attempting to offload at a station already held by another vehicle.

d. The offload station at the truck area receiving station is never used and should be deleted.

e. Eight vehicles can handle the expected workload rather than the 15 originally planned.

3. Nine forklifts be used in the receiving area (assuming no AGVs).

4. Two forklifts be used in the Building 405 receiving area for bulk picks.

5. A total of five man-up turret trucks as opposed to four in the original design.

6. A total of 18 VET inspectors will be required to handle the anticipated workload.

7. Add a second sortation belt to alleviate congestion problems at the merge points.

8. Increase the speed of the final sortation belt, in the event that adding a second sortation belt is not feasible, to allow for increased flow of material to the packing stations (assuming no corresponding increase to the window of belt required per package).

9. Enhance the Seavan Planner to provide for balanced workload among the aisles. Included in this recommendation is that material should be stored in such a fashion as to allow for balanced workload.

10. Study the feasibility of adding packing lanes to the system to allow for increased pick cycle sizes and increased system flexibility and performance.

APPENDIX A

DICOMSS Simulation Technical Report

CONTENTS

LIST OF TABLES

LIST OF FIGURES

I. INTRODUCTION

A. DICOMSS Mission. The Direct Commissary Support System (DICOMSS) provides material support to overseas commissary stores for nonperishable and semiperishable grocery items. Defense Personnel Support Center (DPSC) processes requisitions, aggregates orders, and contracts for material requested by these stores. The DICOMSS warehousing center, located at Defense Depot Mechanicsburg, Pennsylvania (DDMP), serves as a break-bulk point for these items destined for over 70 commissary stores in Europe and the Caribbean. All material handled by this warehousing system is "pre-sold" in that no operating levels are maintained and everything received has already been requisitioned. Material is received, inspected, consolidated, and shipped in seavans to its ultimate destination. Approximately 4,000 items are stored in the DICOMSS warehouse at any one time.

B. Present Warehousing System Design and Problem Areas

The current DICOMSS warehousing system is very labor and forklift intensive. The system employs a Seavan Planner which is a software system designed to batch requisitions for each commissary store of sufficient size to fill a seavan. Stock selectors are dispatched on forklifts with groups of "pick tickets," generated by the Seavan Planner, to build pallets of material. Each pallet is destined for a single commissary. Thus during a day a particular pick facing may be visited many times. As soon as a pallet is built it is driven to a staging area where it is stretch wrapped and moved on to a seavan. During peak workload times, forklift traffic is extremely heavy and, consequently, working conditions are potentially hazardous.

Throughput requirements are expected to increase significantly during the next several years. The present system is already operating at capacity in terms of usable storage space and selection/receiving capability. The incredible volume of forklift traffic has provided an unsafe environment both in terms of collision risks and associated exhaust fumes.

C. DMECSO Proposed Solution

The Defense Mechanization Support Office (DMECSO) was tasked with finding solutions to the system's current problems and providing for the anticipated growth in activity. Improved storage aids are planned to maximize use of available space and allow for better use of higher areas. A pick-to-belt concept is being considered which will eliminate the need for forklifts to be used in the picking process. Stock selectors pick the material, afix bar-code labels, and place the cases on conveyor belts which transport them to a packing lane sortation loop. While at a pick facing, the stock selector may be picking for many different commissary stores. Cases pass a bar-code scanner which directs them to one of six packing stations where they are palletized and put into seavans for further transfer.

Enhancements in the receiving area are being planned as well which include the use of an Automated Guided Vehicle (AGV) system to transport full pallet material across the two building complex to bulk locations. The AGV system is incorporated into the picking process to handle full pallet selections from bulk locations.

D. Objectives of DORO Study. The Defense Logistics Agency Operations Research and Economic Analysis Management Support Office (DLA-LO(DORO)) was tasked to perform a computer simulation of the DMECSO proposed design. Of critical interest was whether the enhancements to the system would meet the anticipated throughput requirements. The system would be checked for potential bottlenecks and trouble spots and with this tool any future contractor enhancements could be checked for feasibility.

E. Scope of Analysis. The simulation was limited to the enhancements made to DICOMSS warehouse space in Buildings 506 and 507. The functions of unloading, receiving, inspection, stowage, consolidation, and loading were modeled. Workload and throughput requirements were projected by DMECSO and utilized as inputs to the computer model.

II. METHODOLOGY

A. Overview

This study employed simulation methodology to provide the necessary results for several reasons. First, the DICOMSS operation is a complex environment involving a myriad of subsystems and resources. As in many complex systems, the dynamics of the factors influencing system operation are difficult to measure without using a simulation approach. Timing is another reason for employing simulation. Since the enhancements were still in the design phase, a flexible approach was needed to test varying alternatives.

It was decided that the system could be simulated as two separate modules, receiving and pick-to-belt. The break between these two sections was decided upon because of the very limited system interfaces in their operations. Also, the current system accomplishes these two functions on different shifts and enhancements will most likely be handled with a similar approach. The only potentially shared resource between the two systems was the AGV system which could be used for performing bulk picks. It was decided that this interface could be represented by statistical distributions. This allowed the model to run more efficiently and provided modeling flexibility.

B. Scenarios Modeled

1. Baseline Design. The baseline scenario modeled was based upon DMECSO projections of DICOMSS workload in the 1990 timeframe. This scenario included the proposed mechanization of Buildings 506 and 507, the

DMECSO plans for enhanced storage aids, and the expected throughput requirements in that timeframe. Individual scenarios modeled under this general framework are discussed below for both the receiving and pick-to-belt operations.

2. Receiving/AGV Module Scenarios

Two basic scenarios were modeled for the receiving operation. The first scenario consisted of the basic DMECSO design and included an AGV system. The second scenario covered the basic design without the AGV system with forklifts performing the AGV functions.

A two step approach was taken in modeling each of these scenarios. The first step involved determining the number of each resource which was necessary to accomplish the workload. In the second step, input requirements (such as the number of trucks per day) were varied to determine the effects on completion times, resource utilization, and overall system effectiveness. The exact combination of resources and requirements modeled under each scenario are discussed in section VI.

3. Pick-to-Belt Module Scenarios. In addition to the baseline scenario, the model was run increasing the final sortation belt speed to 285 feet per minute as requested by DMECSO at the interim project briefing. Early simulation model runs had indicated that the original speed of 200 feet per minute was insufficient to achieve the desired throughput. A scenario with a second sortation belt was also modeled as an alternative to increase the flow of material to the packing stations. Several scenarios were also tested which varied the distribution of workload (picks) among the aisles.

C. Measures Of Effectiveness

1. Overview. Critical to the design enhancements was the ability to handle the anticipated throughput requirements in a timely manner. Therefore, the most critical measure of effectiveness was the time to complete a typical day's work. The effectiveness of various scenarios could be tested by comparing the time to achieve completion of similar throughput levels. Specific measures of effectiveness are listed below.

2. Receiving/AGV Module

The overall question in the DICOMSS receiving area was whether or not the resources could handle the pallet throughput requirements during one shift. Measurements were taken on the time to complete the different receiving tasks. In addition, measures of resource utilization were taken covering the time during which the resource was active. Finally, several lower level measurements were used to further distinguish between alternatives. For instance, for designs including an AGV system, measurements of average time for completion of a single AGV movement were also taken.

Task completion times under baseline input requirements were used to size resources in the first step of the analysis. In the second step of the analysis, other measures such as resource utilization and individual task completion times were compared under different requirements levels.

3. Pick-to-Belt Module

Critical to the pick-to-belt system design is the time to complete a pick cycle. The DMECSO proposed design calls for approximately six batches or cycles of stock selection each day. Since the model assumes no equipment down time, a typical day's work in the pick-to-belt area was assumed to be a group of individual pick cycles.

As in the receiving module, resource utilization is a key measure of performance in the pick-to-belt module. Measuring unproductive time for stock selectors was also considered to be an effective tool for comparing alternatives.

III. DATA DEVELOPMENT

A. Overview

The data development phase involved several meetings with DMECSO personnel, a trip to a similar pick-to-belt system operating in the private sector, background reading into conveyor belt and AGV system operation and capabilities, and formal data requests from DMECSO. During this process, a close interface with DMECSO personnel was maintained to clarify data inputs and explain system operation. An interim briefing prompted further clarification and redirected modeling efforts in several areas. A copy of the formal data request and the DMECSO reply is enclosed as Appendix B.

The specifics of the data collection task were organized in terms of the proposed physical design, resource capabilities and requirements, and other throughput requirements. These data areas are discussed below in terms of the receiving/AGV module and pick-to-belt module.

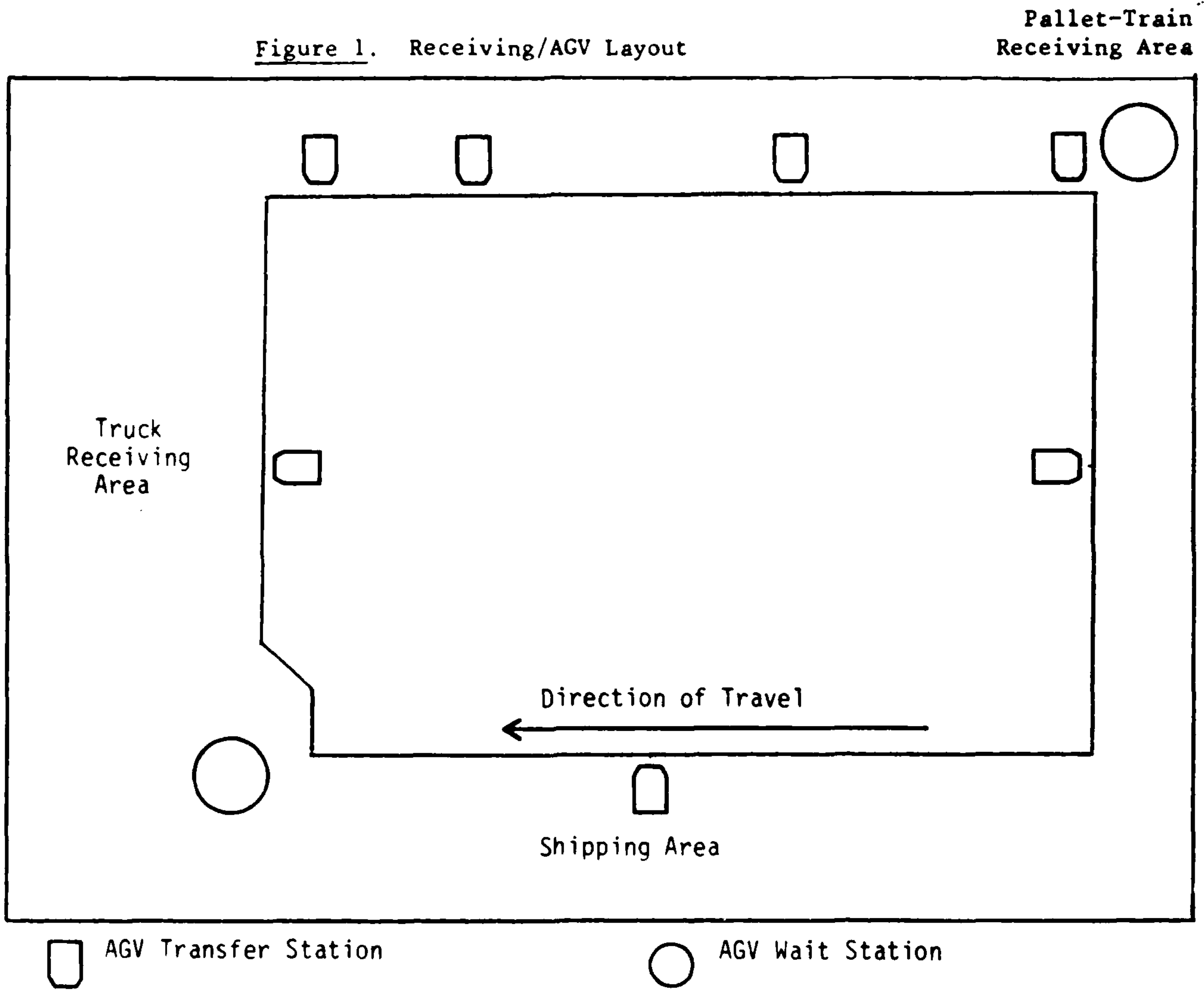
B. Receiving/AGV Module

1. Physical Design

The physical design blueprints were used to model the AGV system. These blueprints provided track layout, numbers of on/offload stations, station positioning, and station design. The physical layout of the proposed AGV system is shown in Figure 1.

In the baseline design, the AGV system track was basically rectangular and followed the outside of the pallet and carton racks. There were seven on/offload stations and two wait stations. With the exception of the shipping area station, all stations had the same basic design which included both an onload and an offload conveyor, each with a capacity of

Figure 1. Receiving/AGV Layout



eight pallets. One conveyor belt brought pallets into the AGV system and the other took them out. The shipping area station differed in the design of the conveyor belt. This station had no onload requirements; therefore, only an offload conveyor belt was required and this belt had a 30 pallet capacity. The wait stations were positioned in opposite corners of the building. The station in the upper right hand corner of Figure 1 was a "holding area only" station where AGVs waited for pallet movement requirements. The station in the lower left hand corner was both a holding area and a charging/ maintenance facility.

The other information obtained from the physical design specifications included appropriate distances between differing action areas and bulk pallet area information. The distances between different areas of the building were used to obtain movement times for the different resources. Bulk pallet area data was used to determine the proportion of bulk pallets in each area of the building. These proportions were used to determine the location of bulk pallet picks as well as the location of potential bulk replenishment actions.

2. Resources

a. Overview. The DICOMSS receiving function was modeled using six different resources: forklifts, man-up turret trucks, AGVs, truck receiving doors, Veterinary (VET) inspectors, and pallet staging space. Each of these different resources is discussed below.

b. Forklifts. Receiving module forklifts were used for offloading trucks, bulk pallet picks, and offloading pallet-trains coming from Building 405. Forklifts and forklift operators were considered as the same entity, therefore if a forklift was available an operator was also assumed to be available. A speed of 5 miles per hour was used for all forklift movements. Acceleration/deceleration of the forklifts was not modeled. Forklift onload and offload times were assumed to be uniformly distributed between five and ten seconds. The module allowed 15 to 25 seconds to onload and offload pallets at an AGV station with a set 10 second key-in time for all onloads.

c. Man-up Turret Trucks. These vehicles were used to replenish the pallet and carton flow racks. Their speed was assumed to be a constant 4 feet per second and the times to accomplish a pallet replenishment to a pallet flow rack were assumed to be uniformly distributed between 15 and 45 seconds which also accounts for vertical distance. Carton flow rack replenishment times were assumed to follow the same time distribution as the pallet flow racks.

d. Automated Guided Vehicles (AGVs). AGVs were used to move pallets among stations. Times for loading a pallet from a station and offloading a pallet to a station were assumed to be a constant 60 seconds. Vehicle speed was assumed to be 4 feet per second (about 2.7 miles per hour). Again, acceleration and deceleration of the vehicles were not modeled.

e. Truck Receiving Doors. Trucks arriving to be unloaded docked at a door at the side of the building. There were a total of 14 doors on the receiving side of the mechanized complex. Therefore, the number of trucks which could unload simultaneously was limited to 14.

f. VET Inspectors. VET inspectors verified that pallets unloaded from trucks were free of pest infestations. Every pallet containing consumable items was required to have this type of inspection before it was accepted into the DICOMSS operation. These inspections were modeled using a uniform time distribution with a minimum of 600 seconds and a maximum of 900 seconds (10 to 15 minutes) per pallet.

g. Pallet Staging Area. Pallets offloaded from trucks were staged in the receiving area for tasks such as VET inspection, pallet rebuilding, detrashing, and pallet breakdown. The number of pallets which could be processed at any one time was limited to 250, based on available space.

3. Input Requirements

a. Overview. Inputs to the receiving model included trucks, bulk pallet picks, and pallet-trains from Building 405. The specific number of each input in the discussion below was determined from the baseline input requirements provided by DMECSO.

b. Receiving Data Requirements

An average of 42 trucks per day were modeled in the receiving area with interarrival times uniformly distributed between 306 and 918 seconds. On the average, seven trucks arrived each hour; however, based on the interarrival distribution, trucks per hour could vary between five and nine. Each truck contained from 16 to 20 pallets (also assumed to be uniformly distributed). Therefore, the average number of pallets processed was 756 per day. These 756 pallets were characterized by the number of individual items (NSNs) contained on the pallet and by the type of storage the item required.

Pallets containing more than one item were broken down into additional pallets (one pallet per item). The distribution of items per pallet affected the total number of pallets which could be processed. Historical data (based upon six months of demand history) on the number of items per pallet showed that approximately 70 percent of the items arrived on multi-item pallets (from 2 to 10 items) and 30 percent of the items arrived on single-item pallets (1 to 110 pallets per item). The characteristics of a receiving pallet were based on this breakdown.

The breakdown of multi-item pallets into one pallet per item resulted in an increase in the average receiving pallets per day from 756 pallets (originally coming off the trucks) to approximately 940 per day. These pallets were used to replenish the bin and bulk areas of DICOMSS.

(i) Bin Replenishment Pallets. Of the total receiving pallets arriving per day, 75 percent were used to replenish the pallet and carton flow racks. These pallets constituted 95 percent of all multi-item pallets and 64 percent of the *single-item* pallets. The bin pallets were distributed across the aisles based on the number of pallet positions within each aisle.

(ii) Bulk Replenishment Pallets. Bulk pallets comprised the other 25 percent of the total receiving pallets. These pallets were made up of five percent of all multi-item pallets and 34 percent of all single-item pallets. The bulk pallets were distributed to the different bulk storage areas based on the number of pallet spaces available within each area.

c. Bulk Pallet Picks. On average, 150 bulk pallet picks were modeled each day. The location of each pallet was based on the distribution of bulk storage area in the mechanized complex. All bulk picks to be processed during the day were assumed to be known at the start of the day. Therefore, there was no arrival process associated with bulk pallet picks. Rather, they were simply processed one after another as a bulk picking forklift became available.

d. Building 405 Pallet-Trains. The final set of pallet inputs which were processed were pallets from Building 405 which arrived in groups of 5 to 10 on pallet-trains. An average of 15 pallet-trains were modeled during the day. The interarrival times were based on a uniform distribution between 1,020 and 3,060 seconds.

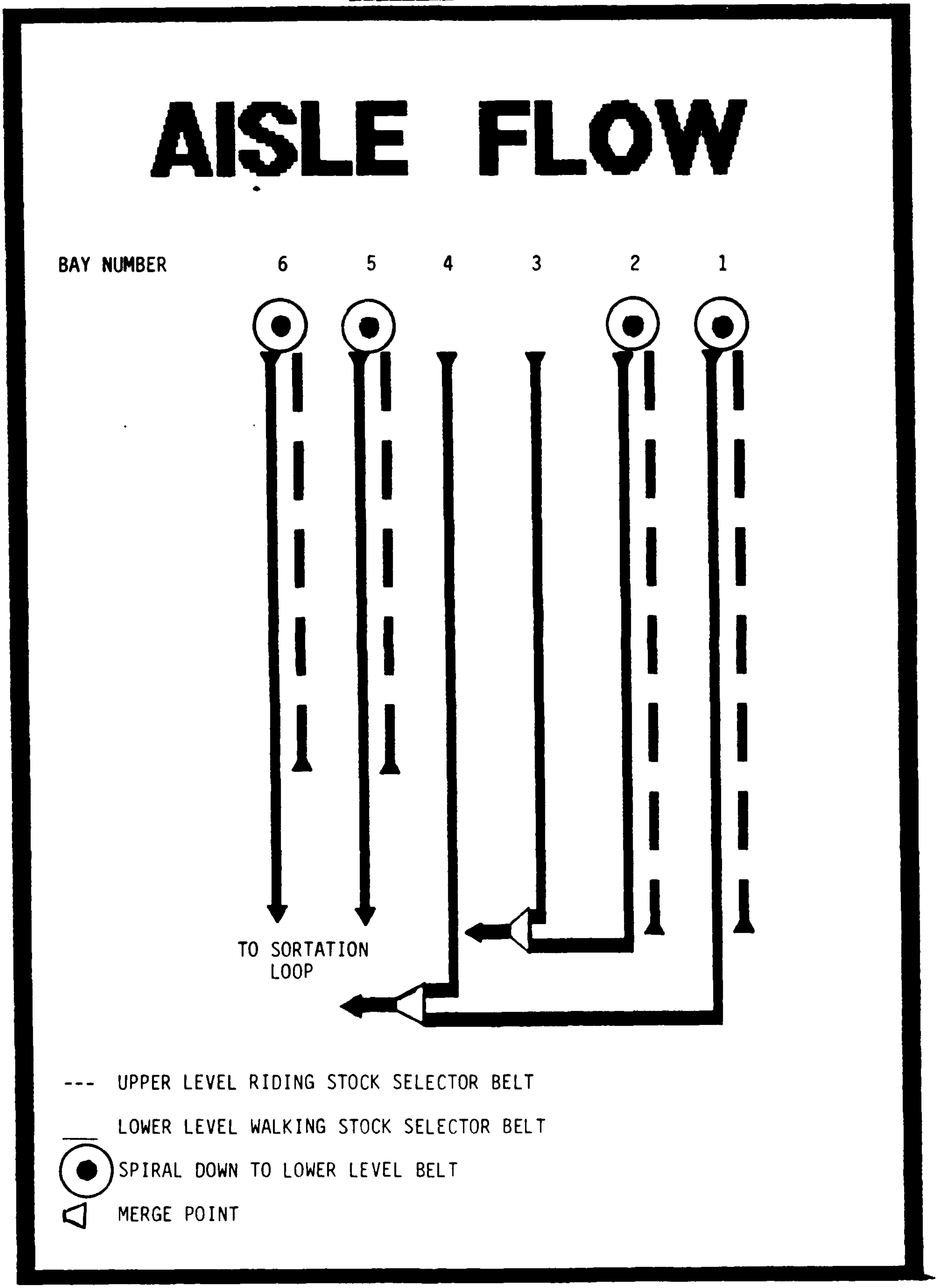
C. Pick-to-Belt Module

1. Physical Design

The two-building DICOMSS warehousing complex was divided into six separate aisles or bays in the proposed DMECSO design. Figure 2 represents a depiction of the aisle layout. Two of the aisles were low bay areas (low ceiling) with each having a dedicated walking stock selector traversing the aisle in a U shape. The walking stock selectors had two levels of pallets to pick from.

Four aisles represented high bay (high ceiling) areas. Each of these aisles had two stock selectors, one of which traversed the floor level in a U fashion similar to selectors in the low bay areas. The other selector rode a mechanized cart through the upper three levels of the aisle, picking from both his right and left on each of the three aisle passes. Two of the four high bay aisles were shorter in length (aisles 5 and 6) to allow room for the sortation belt. The belt utilized by the riding stock selector merged with the floor level walking selector's belt after spiraling down at the end of the aisle.

Figure 2



AISLE FLOW
BAY NUMBER
6
5
4
3
2
1
TO SORTATION LOOP
--- UPPER LEVEL RIDING STOCK SELECTOR BELT
LOWER LEVEL WALKING STOCK SELECTOR BELT
SPIRAL DOWN TO LOWER LEVEL BELT
MERGE POINT

Each aisle was divided into 55 ten foot segments by the model to allow better tracking of case flow. Each ten foot segment of belt was assumed to have a capacity of four cases at any point in time. If the belt segment was at capacity, the stock selector waited until space was available to place his case on the belt. Since the upper level belt of high bay areas merged with the lower level belt, some congestion was possible in this area.

Conveyor belts merged together at various points in the system such that by the time cases reached the main sortation belt they were all sharing the same belt. This implied that congestion could also occur at each merge point.

2. Resources

Conveyer belt segments were modeled as resources; each with a capacity of 4 cases for every 10 feet. It was assumed that conveyer belt speed was 80 feet per minute within the aisle. Accumulator belts were also modeled as resources. However, their capacity was assumed to be one case for every two feet of belt. Merge points were modeled as resources with a capacity of only one case at any given point in time.

Six separate groups of packers were modeled, one group of two for each packing station. Packers performed two functions, pallet building which was assumed to take between 5 and 8 seconds for each case, and stretch wrapping which was assumed to take from 40 to 60 seconds for each pallet (modeled as a "batch" of cases with a total cube of at least 46 cubic feet). Stretch wrapping was assumed to have priority over pallet building but only utilized one of the two packers.

Forklifts were the last resource type modeled. A total pool of ten fork-lifts was modeled in the packing area which performed several functions. First, they removed newly built pallets from the stretch wrap area and loaded them onto seavans which was assumed to take between 40 and 60 seconds. Forklifts were also dispatched to the shipping area AGV station to retrieve bulk picks and pallets coming from Building 405. This process was assumed to take from 40 to 75 seconds based on the distance to the station, a maximum forklift speed of five miles per hour, and the time to onload and offload a pallet.

3. Input Requirements

Data inputs to the pick-to-belt module fell mainly in the stock selection area. Total cases, number of cases from each aisle, the rack locations picked, the number of cases from a given rack location, and the times to accomplish a pick had to be determined for each pick cycle.

The basis for all the stock selection inputs was the standard pick rates expected under DICOMSS. For walking stock selectors, the standard hourly picking rate was 450 cases. Riding selectors on the upper level of the high bay areas were modeled at a target pick rate of 400 cases per hour.

Given these standards, the expected number of cases for a given pick cycle was based on the pick cycle duration. For cycles of one hour duration, the expected number of cases was based on four upper level pickers with pick rates of 400 cases per hour and six bottom level pickers with pick rates of 450 cases per hour. Therefore, over a one hour cycle, the expected number of cases was (4 * 400) + (6 * 450) = 4,300 cases.

The distribution of the total cases across the six picking aisles was generated in one of two ways. In the first instance, the cases were distributed evenly with no regard to the number of pick facings on a given aisle. Every lower level picker would generate 450 cases and every upper level picker would generate 400 cases each hour. The second method used the distribution of pick facings within each aisle to determine the aisle workload. In this instance, the number of cases picked from a given aisle was based on the proportion of pick facings on that aisle to the total pick facings on all aisles. The model assumed that the number of cases selected from an individual pick facing was based only on the number of pallets supporting that facing and not on the aisle in which it was located. This second instance was especially significant in aisles 5 and 6 (see Figure 2) where one third of the available space for storage was set aside for accumulation and sortation space.

Within these two options, a sensitivity analysis was performed on the deviation of workload among the aisles. This involved a random deviation from expected picks under the assumption that the seavan planning function (which currently generates pick cycle workload drops) would not be able to distribute workload evenly across the aisles due to computer software limitations. This was modeled as a percentage deviation from the expected picks and allowed random deviation in the stock selection process for both of the above input options.

Given the number of picks from a particular aisle, the next set of inputs involved the timing of the individual picks. This process involved three steps: determining which locations were to be picked, determining the number of cases picked from each location, and determining how long it took the selector to accomplish the activities.

The specific locations of active pick facings during a particular pick cycle were determined as follows. First, the total number of active pick facings was determined by dividing the available facings by the average picks per facing. The total number of pick facings was dependent on the aisle and the level (bottom or top). The average picks per facing was based on five cases per active pallet at that facing. This mean was based on the number of commissaries picked in a given cycle and the average number of cases on a pallet. For single deep pallet flow racks the average cases to pick per facing was five, for double deep pallet flow racks the average cases per facing was ten, and so on. The locations for the active pick facings were determined randomly using the percentage of active pick facings as a basis. This ensured a uniform distribution of workload across the pick facings for a given aisle.

Cases per active pick facing were then generated using a Poisson distribution with a mean of five times the number of pallets supporting that pick facing (i.e., single deep, double deep, etc.). Given the pick locations and the number of cases to be picked from each location, the next step was to generate the actual pick times.

Actual pick times were modeled as a combination of three distinct time increments: location time, travel time, and case picking time. Location time was defined as the time it took the selector to find the next active pick facing. These times were generated from a uniform distribution with a minimum of one second and a maximum of six seconds. Travel times were based on the speed of the selector and the distance to the next active facing. A speed of 0.8 pick facings (approximately 4.25 feet) per second was used for a bottom level walking picker and 1.0 pick facings per second was used for a upper level riding selector.

Once the selector located and traveled to the next active pick facing the actual picks were accomplished. A picking action consisted of peeling a bar code label off a pick ticket, affixing it to the case in a specific location, and placing the case on the conveyor belt. Pick times for a walking stock selector were modeled as a uniform distribution with a minimum of three seconds and a maximum of five seconds. Since the walking stock selectors had two levels of pallet facings to pick from and the higher level was considered to be more difficult, 0.75 seconds were added to the pick time for these higher facings. Pick time for a riding stock selector was modeled as a uniform distribution with a minimum of three seconds and a maximum of six seconds.

Small amounts of time (10 to 30 seconds) were added to between 10 and 15 percent of the travel times to allow for lapses in performance. Time was also added to remove empty pallets from the pick cart (riding pickers only) at the end of the aisle before raising to the next pick level.

Considerable effort was expended to ensure that the set of inputs discussed above provided a realistic representation of the actual process and the time involved in each aspect of the actual process. These times were based not only upon DMECSO inputs but also actual observations of a similar pick-to-belt facility in the private sector. Verification of these inputs showed hourly pick rates which were very close to the DMECSO projected rates.

Other basic input requirements are specifically delineated in Appendix B. All distances and speeds were modeled in keeping with the DMECSO design specifications. Speed of accumulation belts was increased by 20 feet per second after each merge point with a final sortation belt speed of 200 feet per minute in the baseline scenario. Packing station belt speeds were assumed to be 80 feet per minute.

IV. RECEIVING/AGV MODULE LOGIC FLOW

A. Overall System Description. The receiving module incorporated logic to handle new receipts, pallets received from Building 405, and the AGV system. Pallets were modeled as entities with certain characteristics which control its future activities. The module handled four different types of pallets. The first two types were bin and bulk replenishment pallets from the truck receiving portion of the module. The last two types were full pallet (bulk) picks and manually built pallets from the nonmechanized portion of DICOMSS (Building 405). Both of these types were handled using the AGV system logic. The specific logic used to process these four types of pallets is discussed below.

B. Modeling Approach

1. Truck Processing

The majority of the pallets processed in the receiving module are pallets unloaded from trucks. The first step in processing the trucks was to unload the pallets. Forklifts were used to accomplish the unloading task. The truck arrival process allowed multiple trucks to be unloaded at the same time. The module limited the number of forklifts which could unload a single truck simultaneously to two. After a pallet was unloaded from a truck it was assigned an attribute which determined whether the pallet would be sent to bin or bulk replenishment areas.

The logic for assigning the bin or bulk characteristic was designed to provide two separate input characteristics. First, based upon historical data, the total number of pallets received was approximately two times the number of items received per day. Second, the ratio of bin replenishment to bulk replenishment pallets was approximately three to one (i.e., 75 percent bin replenishment). After the bin/bulk characteristic was assigned, these pallets were processed through initial inspection, multi-item pallet breakdown, VET inspection, and stow.

The initial inspection was performed by the forklift operator and was merely a quick check for obvious damage and quantity discrepancies. The next step is to break down pallets with multi-items. The result of the breakdown process was that each pallet contained only one item. After initial inspection and pallet breakdown were accomplished, the pallets were staged for VET inspection. At this point the forklift was freed to accomplish other activities.

The VET inspection involved opening one or more cartons on a pallet and checking for pests, damaged packages, etc. The VET inspection was done on consumable items only. These items accounted for approximately 70 percent of the pallets processed. Each pallet of consumable items was inspected including every pallet of multi-pallet items. After the VET inspection process was completed the pallet was again staged to be stowed in the bin or bulk replenishment areas. The logic for processing pallets through truck receiving is depicted in Figure 3.

Figure 3. Logic for Processing Pallets Through Truck Receiving

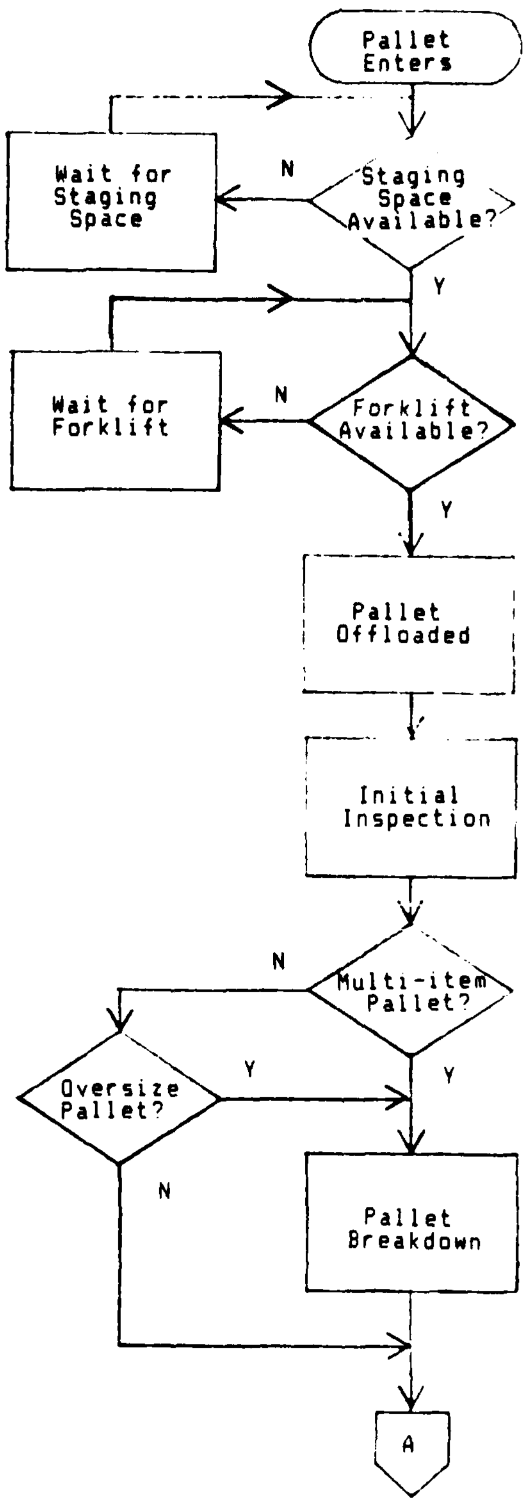
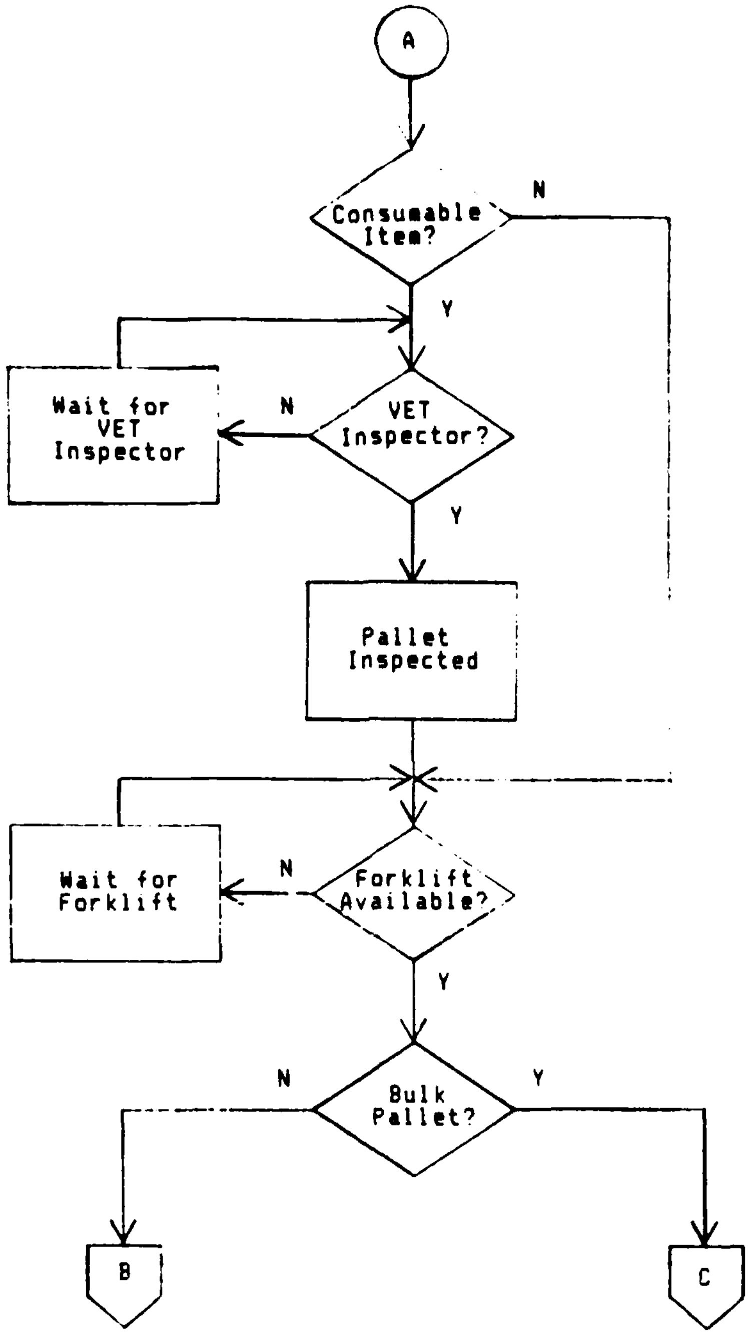


Figure 3. (Continued)



2. Bin Replenishment

Bin replenishment pallets were destined for the pallet racks and carton flow racks which fed the pick-to-belt module. These pallets waited for an available forklift, were loaded on the forklift, and transferred to the appropriate aisle staging area. There were eight rack areas to be replenished, spaced throughout the two-building mechanized complex. The aisle to which a pallet was taken was based on the distribution of pallet and carton space available on the eight replenishment aisles. For instance, the aisles which replenished two sides of the high bay areas received a larger portion of the bin pallets than aisles which replenished a single side of the low bay areas.

The bin pallets were staged at an aisle and the forklift was again freed to accomplish other activities. The staged pallets waited for a man-up turret truck to accomplish the actual stow. The process entailed loading the pallet from the aisle staging area, locating the particular destination within the aisle, traveling to the destination, and placing the pallet (cartons) into the pallet rack (carton racks). The logic for processing bin replenishment pallets is depicted in Figure 4.

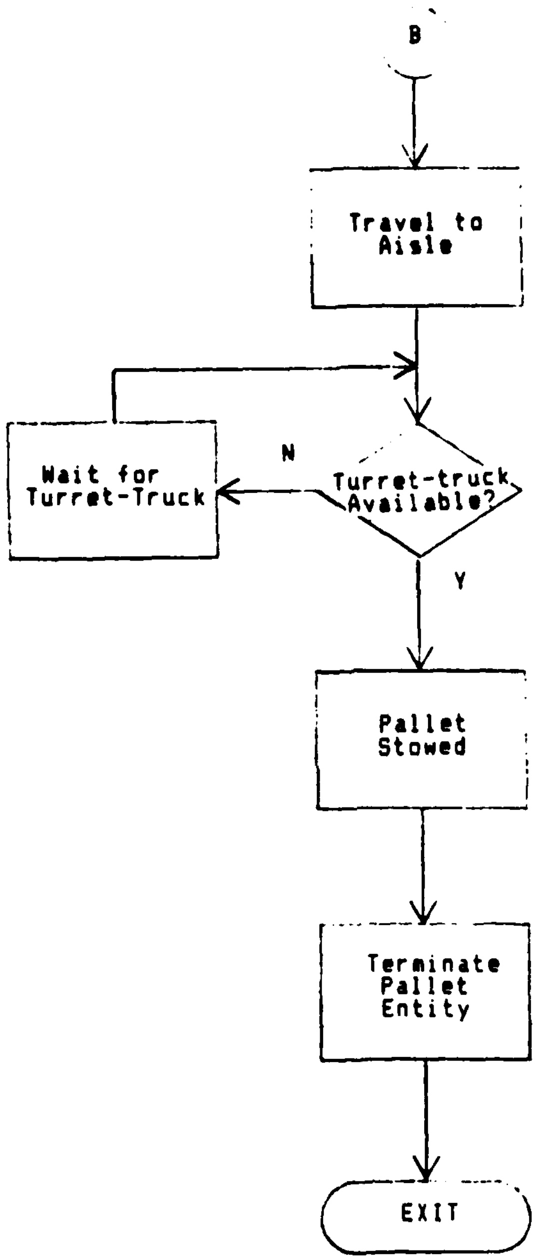
3. Bulk Replenishment

Handling of bulk replenishment pallets depended on the pallet destination within the bulk storage areas. Pallets destined for bulk storage areas on the receiving half of the mechanized complex were handled by receiving area forklifts only. Pallets destined for bulk storage areas on the opposite half of the building were transferred across the building on an AGV and from there were stowed using forklifts from the Building 405 receiving area.

Bulk pallets destined for storage areas on the receiving half of the building waited for an available receiving area forklift. The pallets were loaded onto the forklift, traveled to their destination within the bulk storage area, and were offloaded. The pallet destinations were based on the distribution of bulk storage area on the receiving half of the building. Approximately half of this area was in the middle of the building and the other half was toward the north end (see Figure 1) of the building. Forklift travel times to and from the bulk storage area were based on the distance from the truck receiving area to the storage location.

Bulk pallets destined for storage areas on the opposite half of the building were handled using the AGV system. These pallets waited for an available receiving area forklift, were loaded on the forklift, and traveled to the least utilized receiving area AGV station. The forklift operator transferred the pallet to the AGV station, keyed in the destination station, and returned to the receiving area to process other pallets.

Figure 4. Logic for Processing Bin Replenishment Pallets



After the pallet was transferred across the building on an AGV a forklift from the Building 405 receiving area offloaded it from the AGV station, traveled to the bulk storage destination, and accomplished the stow. The logic for processing bulk replenishment pallets is depicted in Figure 5.

4. Bulk Picks. Bulk pick pallets were located, loaded onto a forklift, transferred to the nearest AGV station, and sent by AGV to the shipping area. These pallets were handled in sequence by a single dedicated bulk picking forklift. After the dedicated bulk picking forklift accomplished all the picks it was transferred to the receiving area to help with truck offloading and replenishment actions. The logic for processing bulk picks is depicted in Figure 6.

5. Pallets From Building 405. The final type of pallets modeled were those transferred into the mechanized complex from the nonmechanized portion of DICOMSS (Building 405). These pallets came into the system in the north corner of the building. They arrived on pallet-trains and were unloaded, taken to an AGV station, loaded onto the AGV station, and transferred to the shipping area on an AGV. The logic for processing pallet-trains is depicted in Figure 7.

6. AGV System Logic

The AGV System was modeled as a set of resources. Requests for pallet movement on the AGV system were given a priority of one or two with one being top priority. Pallet movements to the shipping area were the top priority and took precedence over other movement requests. Bulk replenishment pallet transfers from the truck receiving side of the building to the pallet-train receiving side of the building were given lower priority.

Each vehicle in the system had an associated status. The status codes and their definitions are given in Table 1.

Table 1

AGV SYSTEM STATUS CODES

AGV Status	Definition
1	Loaded and moving to destination.
2	Unloaded and moving to pallet.
3	Unloaded and waiting.
4	Unloaded and moving to a wait station.
5	Unloading pallet at destination.
6	Loading pallet at origin.
7	Waiting to unload at destination.
8	Waiting to load at origin.

Figure 5. Logic for Processing Bulk Replenishment Pallets

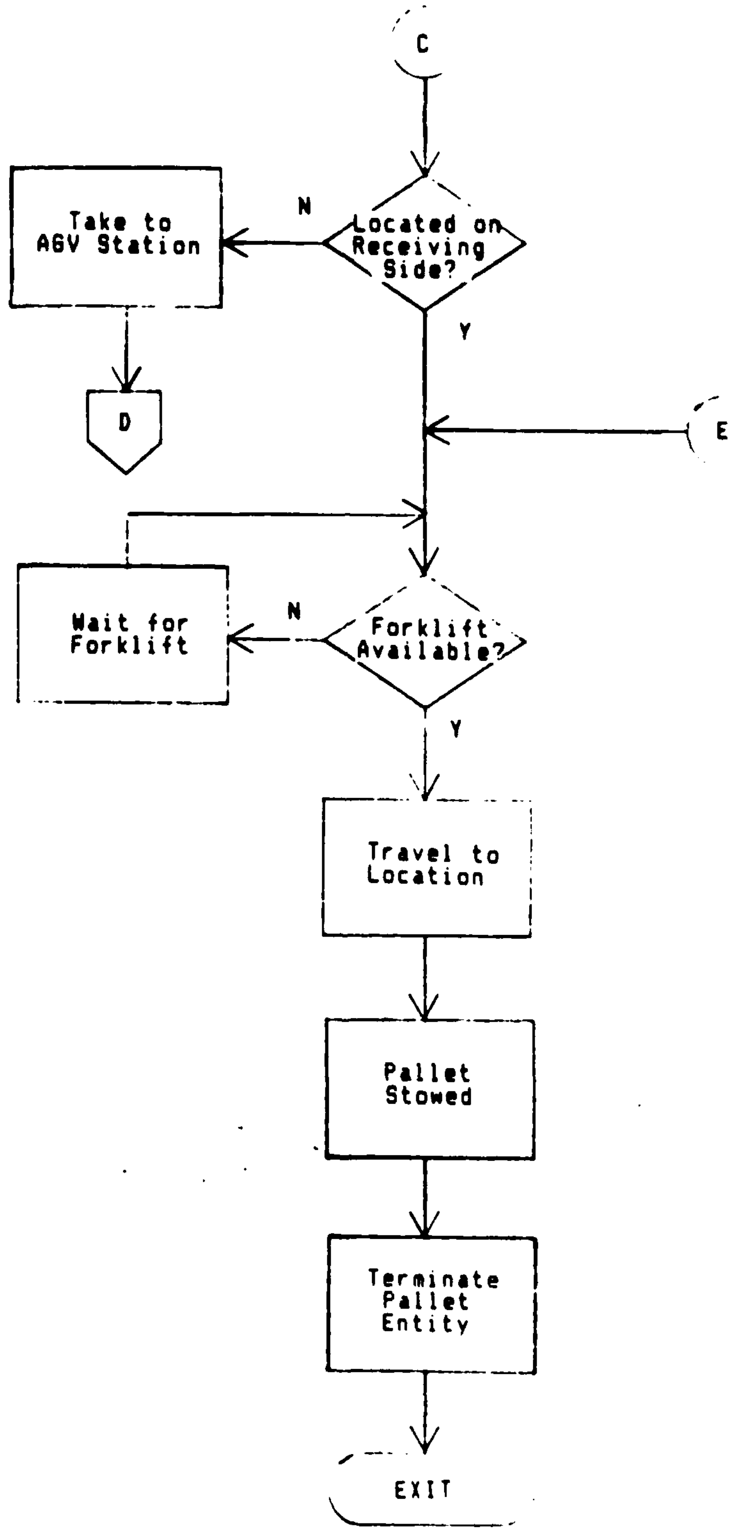


Figure 6. Logic for Processing Bulk Picks

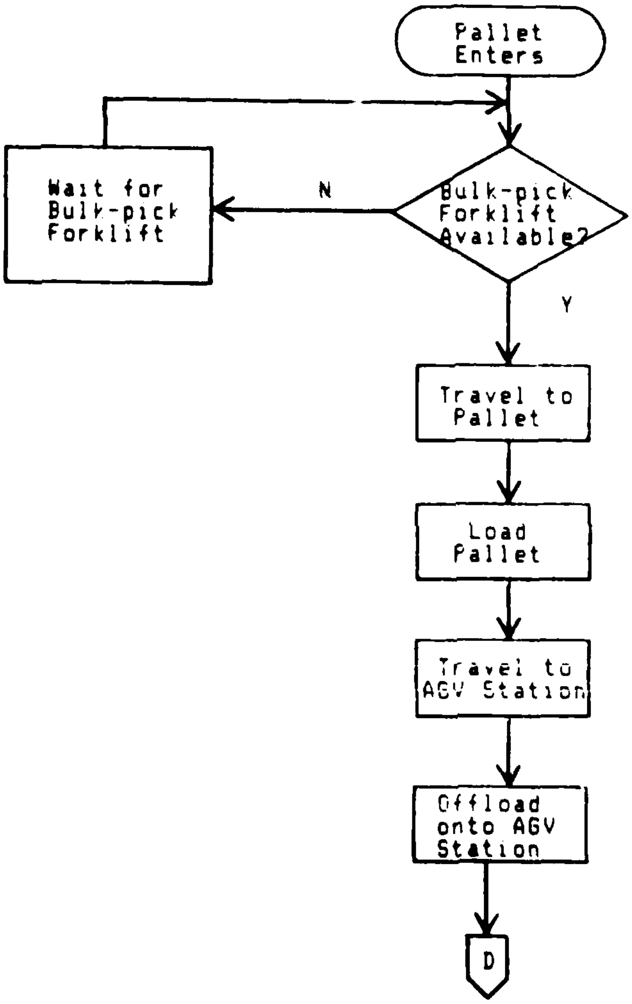
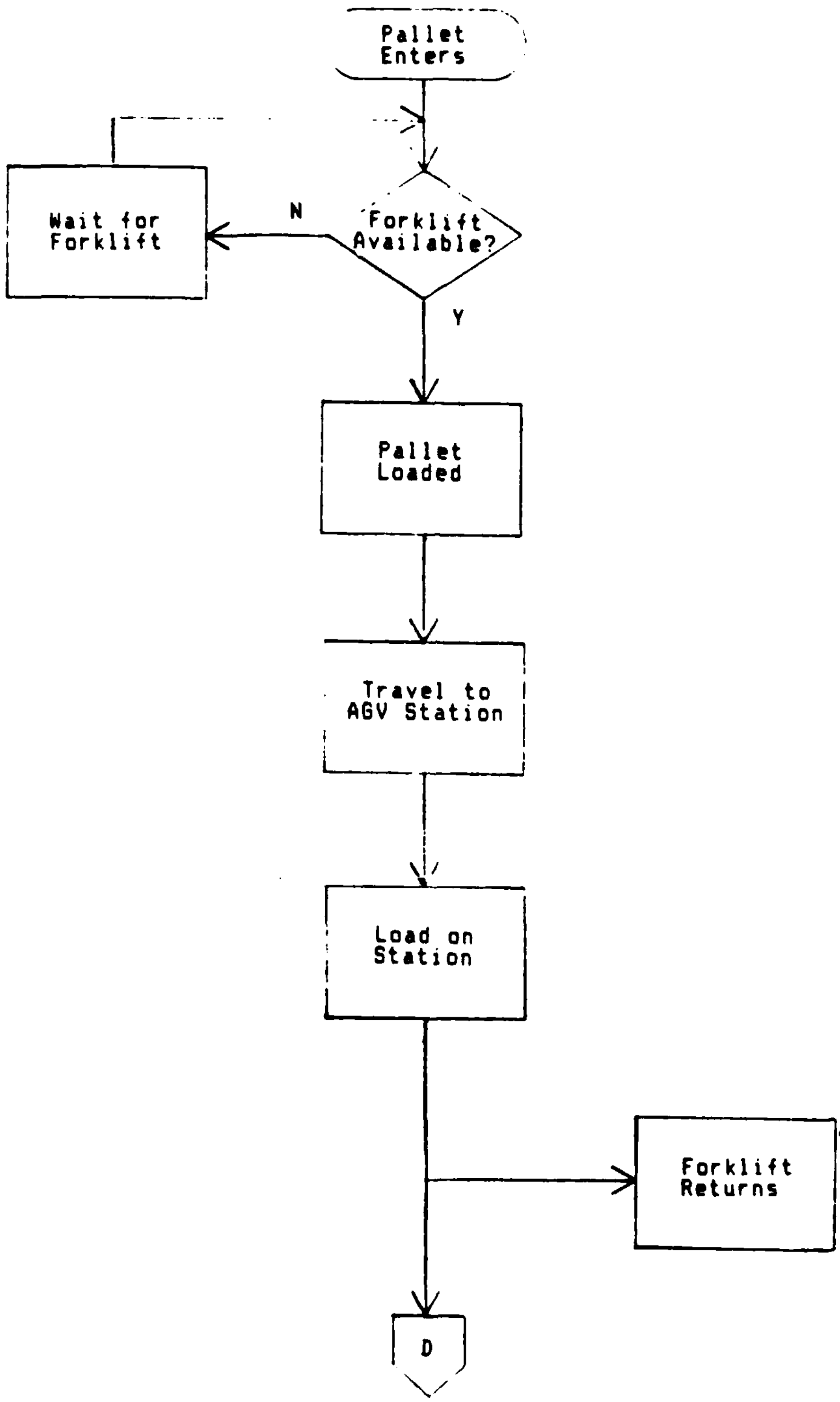


Figure 7. Logic for Processing Pallet-Trains



Vehicle movement requests were satisfied by determining the vehicle which could arrive to load the pallet in the shortest amount of time. The current status of the vehicle could be any of the eight valid status codes listed in Table 1. For this reason, a pallet request could occur without prompting a vehicle in status codes 3 or 4 to respond.

As a vehicle finished unloading a pallet it changed from status 1 to status 4 and moved to the station with the least number of AGVs waiting. However, if a previous movement requirement identified this vehicle as being able to respond in the shortest amount of time, the vehicle responded to that requirement. In this way, response time was close to optimum which in turn provided close to optimum AGV efficiency.

Preemption was possible for priority one movement requests. The vehicle which was identified for the movement was preempted if it was currently moving to load (status 2) a priority two pallet. Preemption could only occur up to the time the vehicle began loading a pallet. After loading was completed, a vehicle remained in status 1 until it was able to offload at the destination AGV station. The AGV system logic is depicted in Figure 8.

C. Key Assumptions

As in any major modeling effort, some assumptions about the actual system had to be made. These features and assumptions are discussed below in terms of module inputs and module logic.

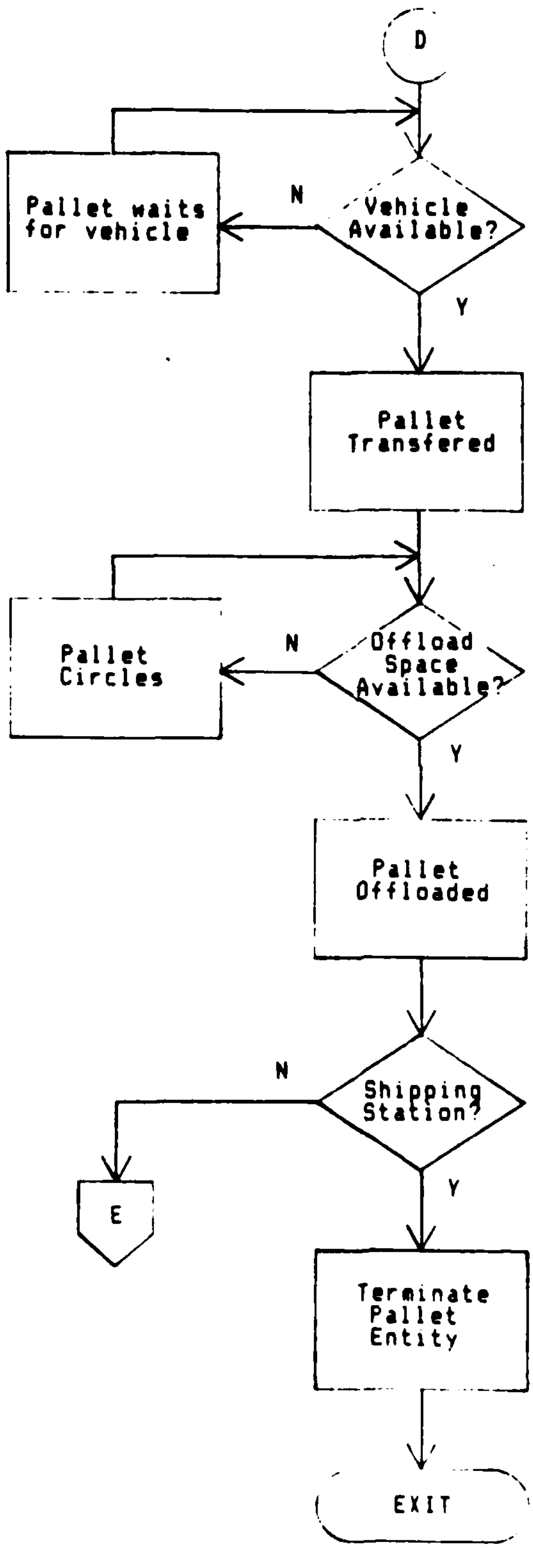
The key input characteristic in the truck receiving area was the proportion of bin to bulk replenishment pallets. A critical assumption in this area was that the present breakdown of bin to bulk pallets would remain proportionate. The other pallet inputs were the number of bulk picks and the number of pallet-trains which were processed on a daily basis. Changes to any of these inputs could significantly change the resource sizing results which were obtained.

Another important assumption made about model inputs was that the inter-arrival distributions of trucks and pallet-trains were assumed to be uniform across a day. Changes in these arrival distributions could cause a significant increase in pallet backlogs.

A key assumption in the model logic was that congestion did not affect forklift travel times. Congestion could occur when pallets were staged in the receiving area, staged for aisle replenishment, when the usage of bulk storage areas increased, or when the number of forklifts increased. The activity times for processing pallets were not dependent on these congestion factors.

Another important assumption involved AGV system modeling logic. The AGV system was assumed to be quick with respect to response time. This assumption could impact the timeliness of AGV pallet movements. However, the affect on AGV resource sizing results is probably small.

Figure 8. AGV System Logic



D. Model Verification

Model verification involved several stages. After debugging the actual computer code, the first step in model verification was to ensure the inputs were being modeled correctly. Extensive model output checking was used to verify that pallet characteristics and resource usage times were portrayed realistically.

The second step in the model verification process was to ensure the logic was correct. Extensive model output checking was again used to verify that logical processing of the various pallet entities was indeed in accordance with specifications.

The final verification step was to ensure that the model outputs made sense. In this step, various combinations of resources and input requirements were modeled. The model outputs were compared across the various resource/input requirement combinations to check module sensitivity. For instance, adding receiving area forklifts should (and did) decrease the time for truck processing.

Validation involves the comparison of model results to real world results. Since the DMECSO design is not yet operational and no other real world system is similar enough to compare results, this type of comparison was impossible.

V. PICK-TO-BELT MODULE LOGIC FLOW

A. Modeling Approach

1. Overview

Case selections were generated after delays based upon stock selector travel time, bar-code application time, and various other factors affecting worker speed. Once cases entered the conveyor system, they were tracked through various merge points and accumulator belts. The baseline system design called for all cases to merge into one master sortation belt loop where bar-codes were scanned and cases were sent to appropriate packing lanes. The final process involved the building of pallets and packing in seavans.

Each case in the computer model was considered to be a separate entity which carried with it various attributes such as unit cube, place of entry in the system, current location within the system, next intended destination, and time of generation. Conveyor belt space, merge points, accumulator belt space, packers, and forklifts were considered to be resources which the entities (cases) attempted to seize or utilize during their time in the system.

Availability of space on the belts was determined not only by the number and location of cases on the belts but also by whether or not the belt was moving or blocked. Open and shut conditions were placed on the flow of entities over these belts by the use of simulated gates. When a flow gate was closed, entities were denied access to that conveyor belt. This situation would occur in the real system if the accumulation belts were filled causing a shutdown of the belt to which the stock selector was picking.

Flow gates were also used to simulate a system monitor at the sortation loop. The system monitor opened and closed these gates based upon given conditions in the model. Detailed descriptions of model logic will be discussed in Section V.

2. Stock Selection Process

As previously mentioned, each individual case was modeled as a separate entity with specific attributes. One particularly important attribute was its initial point of entry into the system. Each entity was assigned to a particular belt segment within the aisle based upon its storage location. When the stock selector completed the travel time to that location or segment, time was allocated for him to afix the bar-code label and accomplish the picking action. The stock selector then made certain the belt was moving and space was available before he placed the case on the belt. As soon as the case was placed on the belt the next selection action was planned.

Figure 9 shows a schematic diagram of how the selection action was actually modeled. The time of the first stock selection was scheduled. As the action was completed the next selection was scheduled based upon the stock selection time offsets previously discussed in the data development section (paragraph III.C.2.). Before a case could be placed on the belt the selector checked the status of the flow gate to ensure the belt was moving and ensured that adequate space was available on the belt. If a problem existed he waited until normal conditions existed before placing the case on the belt. Upon completion of this waiting he was free to schedule the next selection.

3. Conveyor Belts. Perhaps the most critical modeling approach was that of the conveyor belts. Once a case was placed on a belt segment within the aisle it traveled sequentially through the remaining belt segments over time. Figure 10 shows how this activity was modeled. A case entered the system, traversed its initial belt segment, checked the status of the flow gate, attempted to seize a portion of the next segment, freed its portion of the previous section, and looped through the rest of the segments to the end of the aisle. If queueing conditions ahead caused blockages, flow gates were closed and entities were frozen in their current positions in the aisles until conditions were alleviated.

Figure 9. STOCK SELECTION LOGIC

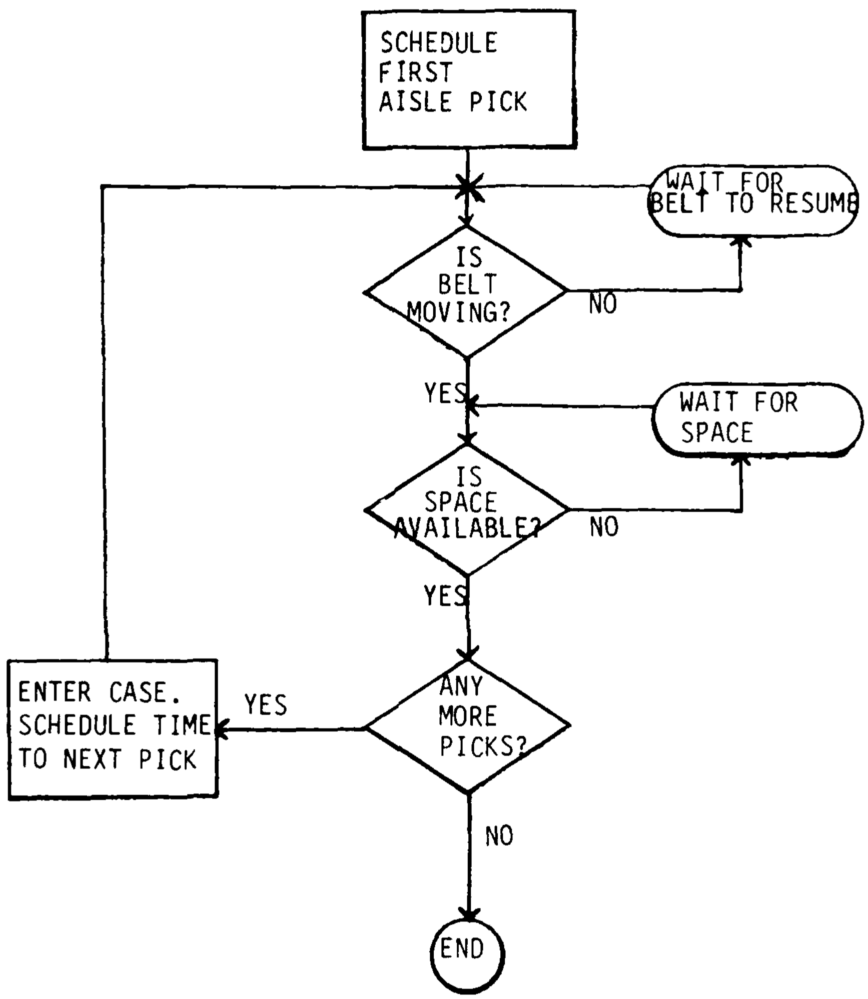
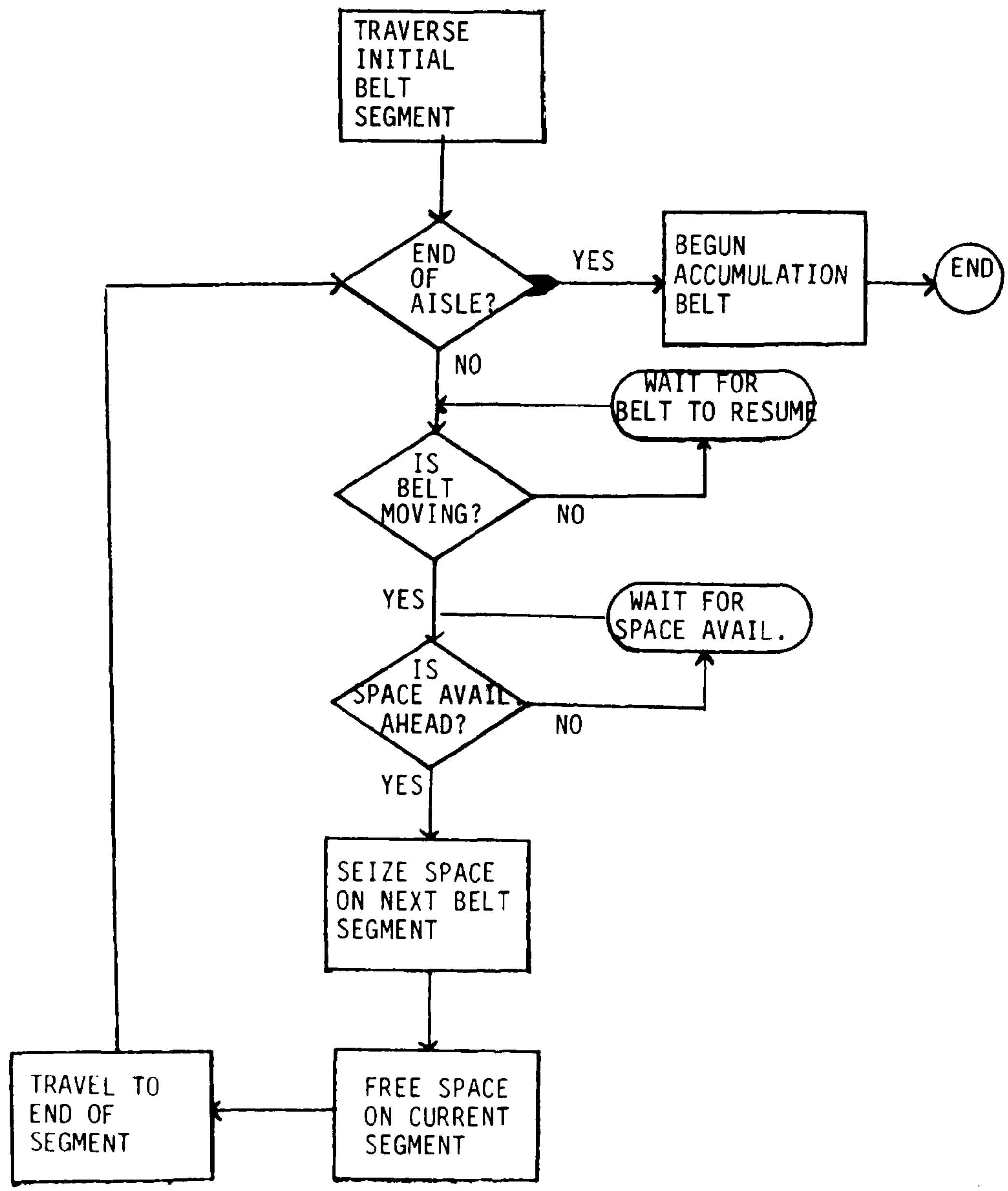


Figure 10. AISLE CONVEYOR BELT LOGIC



4. Conveyor Belt Merge Points

When two belts merged, only one entity passed through that point at any given time. An entity in effect seized a merge point for a window of time called its Unit Move Time (UMT). UMT for purposes of the simulation was a function of the speed of the takeaway conveyor and the spacing between boxes required by the system hardware. Since the timing mechanism of the actual merge point hardware was fixed, the model assumed that the window seized must be larger than the maximum case length (about two feet) traversing the merge point. Based upon discussions with DMECSO, a window of three feet was assumed. UMT is the time it took to travel this three foot window at the takeaway conveyor speed.

Figure 11 displays a representation of how merge points were modeled. If the merge point resource was being utilized, other cases waited in queues on their respective belts until the resource was available. These cases took up space and could inhibit the ability of trailing cases to move.

5. Accumulation Belts. From the end of each aisle to the final sortation belt was assumed to be an accumulation belt. The time it took for a case to traverse these belts was important in determining system performance. Accumulation Belt Traversal Time (ABTT) was defined to be the travel time from the beginning of the belt to the end of the queue line plus the time waiting in queue (ABTT = TT + QT). It is important to note that the travel time was a function of queue buildup and could in fact be 0 if the accumulation belt was full and, consequently, ABTT could potentially be waiting time only. This phenomenon was true because of the fact that once a case began waiting in line on an accumulation belt it moved dynamically as it waited. Figure 12 shows how this physical process was translated into the model.

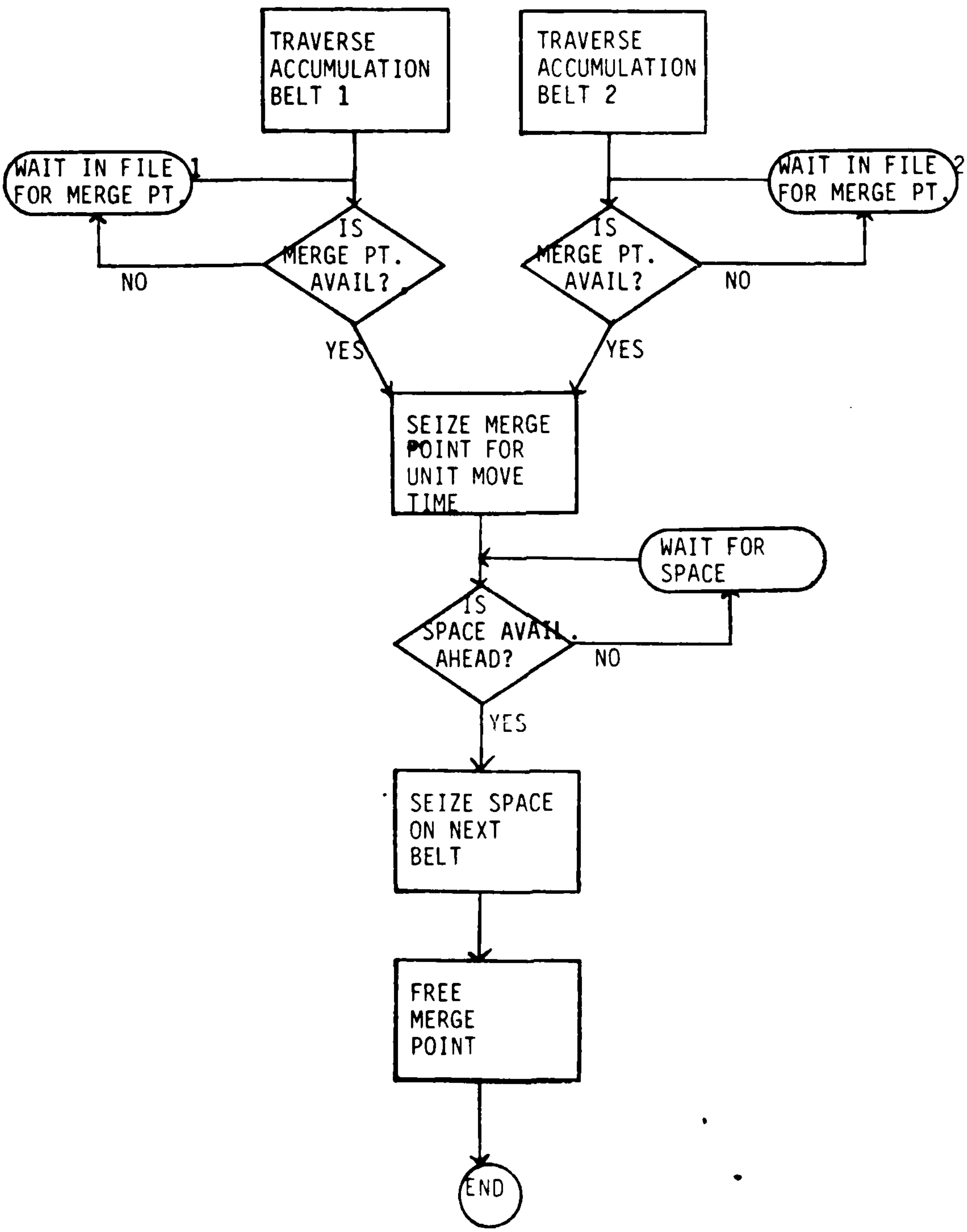
6. Flow Monitor

The baseline design called for a flow monitor stationed at the sortation belt loop. This individual's job was to make decisions about which belts to allow to flow during the pick cycle. Based upon queueing conditions, the flow monitor shut down certain belts to allow other belts to clear.

The flow monitor's decision criteria in the model was to allow the system to free flow until an accumulation belt was over 75 percent of its capacity. At this point the flow monitor gave precedence to this belt by halting the flow of other belts at strategic points. If more than one belt was at 75 percent of capacity, priority was given to the belt with the least amount of accumulation capacity. When override conditions occurred, the appropriate belt was given 45 seconds of priority before the system was allowed to resume free flow.

Flow gates were once again used to model this process. Figure 13 displays the physical layout of the sortation loop and associate flow gates and merge points. Before an entity could attempt to seize a merge point, it

Figure 11. MERGE POINT LOGIC



NOTE: IF ENTITIES ARE WAITING IN BOTH FILES, GIVE PRIORITY TO BELT WITH THE LEAST ACCUMULATION SPACE.

Figure 12. ACCUMULATION BELT LOGIC

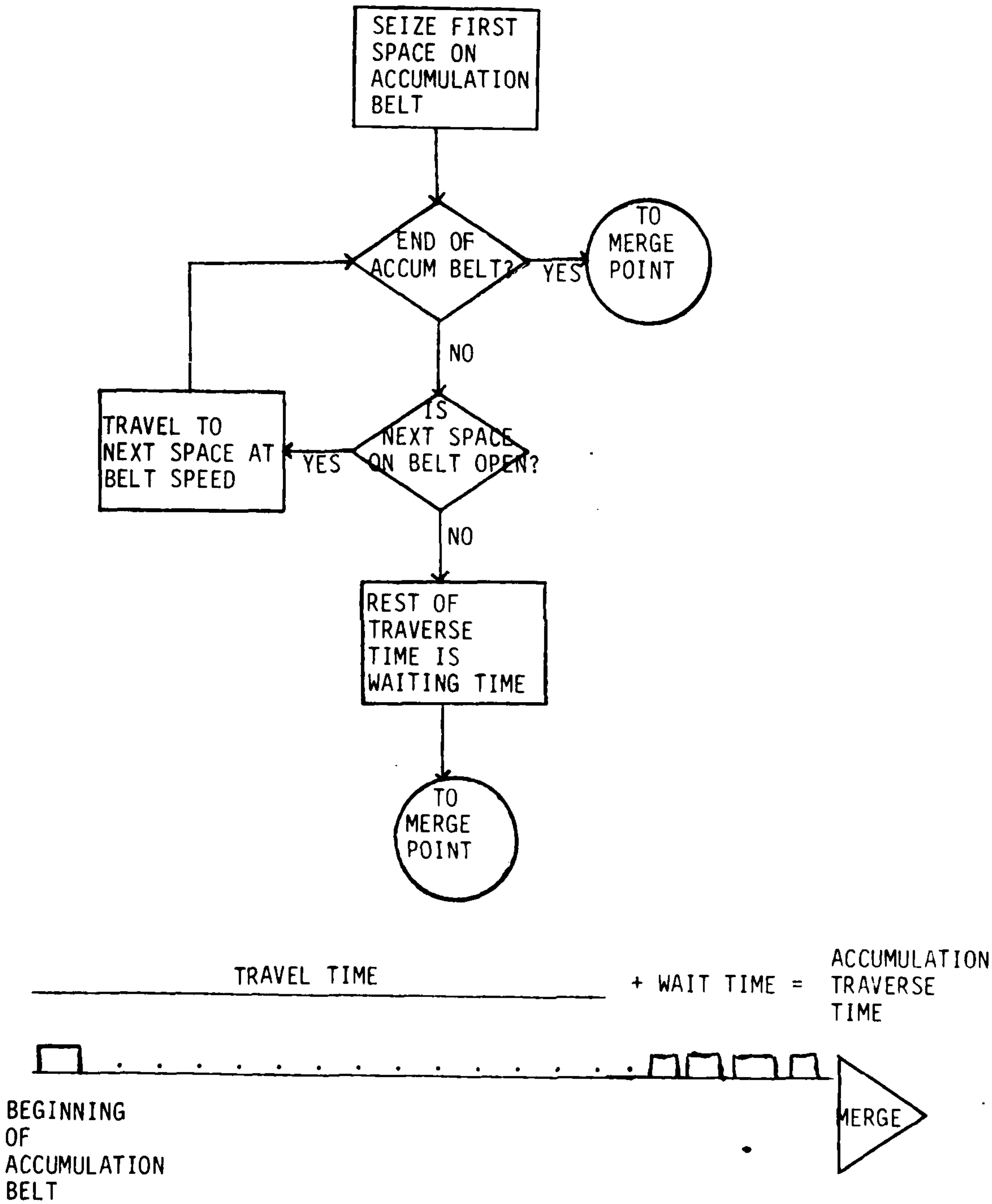
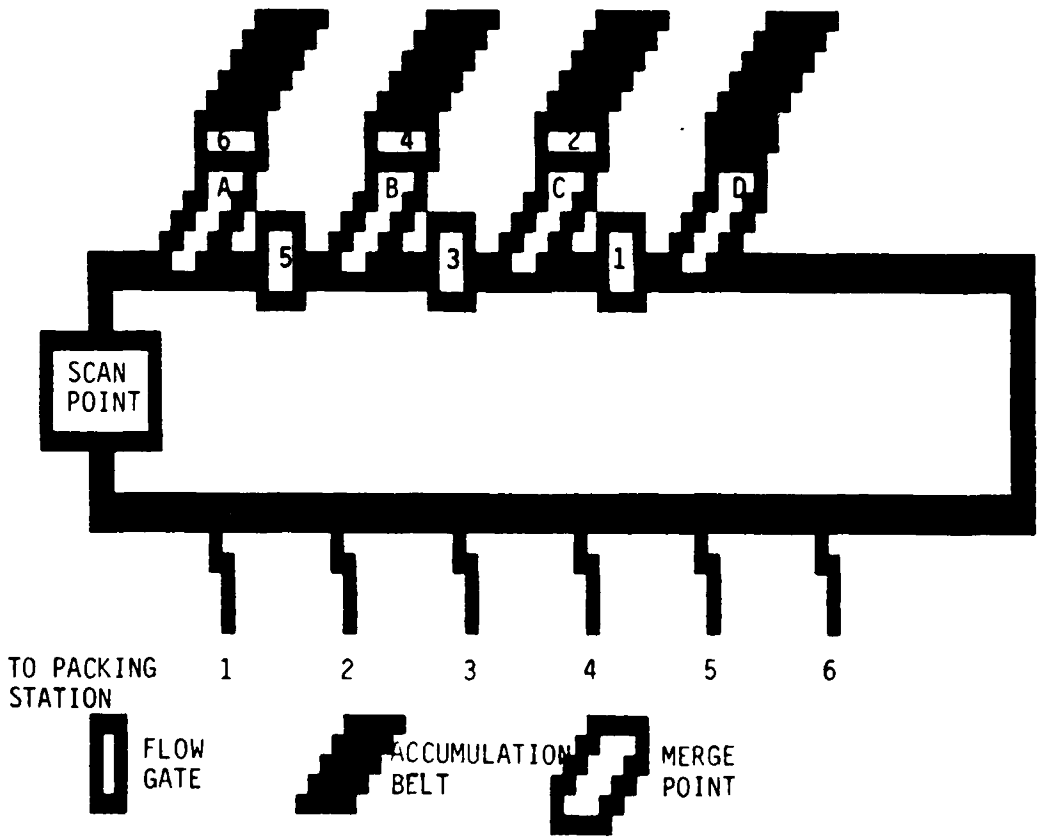


Figure 13

Flow Gates

SORTATION BELT LOOP
- BASELINE SCENARIO

ACCUMULATION BELT	A	B	C	D
FROM BAYS	5	6	2,3	1,4
BELT CAPACITY (IN CASES)	88	68	274	238



first checked to see if its flow gate was open. If the flow gate was closed, entities waited for the override conditions to be halted before proceeding.

7. Packing Lanes. Packing lanes were modeled as queues with capacities of one case for every two feet of belt (maximum capacity of 42 cases per packing lane). Packers were modeled as resources who perform two functions, pallet building and stretch wrapping. As entities reached the packers, they were selected and placed on pallets. A pallet was modeled as a batch of entities with a total space requirement of 46 cubic feet. As a pallet was completed, one of the two packers at a station covered the pallet with stretch wrap and sent it to a forklift for further transfer to a seavan.

B. Key Assumptions

Several assumptions were made which have significant impact on the modeling effort. The first major assumption was that a stock selector will only put a case on the ten foot section of belt directly in front of the pick location. If that belt section was at capacity or the entire belt was stopped, the selector waited until the belt was moving and space was available on the segment. This implied that a stock selector would not walk any distance with a case just to find an open spot and would not overload a halted belt. It is also assumed that each ten foot segment within an aisle had a capacity of four cases.

A critical assumption was that a case seized a merge point resource for a distance of three feet. As previously discussed, this assumption was made to allow for the hardware restrictions on minimum distance between cases (bar-code labels) and the fact that the merge point utilized a fixed time for release of cases from previous accumulation belts. Incorporated into this assumption is that the diverters will be able to handle the workload given this short window and a fast belt speed.

Another critical assumption was that the Seavan Planner would be able to balance the workload among the aisles within some tolerance. Implied in this assumption was that material would be stowed in such a fashion as to make this balancing possible. Neither of these assumptions are supported by the Seavan Planner in its current form.

The model assumed the system experienced no mechanical failures. The model also assumed that, whenever possible, priority at merge points was given to the oncoming belt with the least accumulation space. Additionally, the model assumed that one seavan was assigned to each packing lane per pick cycle.

C. Model Verification. Flow data was collected at various positions in the model to verify direction and timing of entity movements. Several weeks of logic checks and test runs were made to help verify the model. Interim results and model design were reviewed with DMECSO for accuracy, completeness, and overall realism. Sensitivity analyses were performed on critical modeling points to monitor realism.

VI. RECEIVING/AGV MODULE RESULTS AND ANALYSIS

A. Overview

The presentation and analysis of simulation results is divided into four areas. In the first area observations are made concerning the AGV system design. These observations were the result of the model building process and affect the model results which follow. The second section discusses observations based on model verification runs. The last two sections cover how the number of resources was determined and how changes to the baseline pallet handling requirements affect system performance.

Two basic scenarios were modeled. The first scenario covers the DMECSO design including the AGV system. The second scenario models the system without an AGV system. In this scenario forklifts handled all pallet movement requirements.

B. Initial Design Assessment

The model building process identified two changes to the original DMECSO AGV system design. The first change involves the direction of travel of the AGVs on the guidepath. The second change involves AGV station design.

The direction of AGV travel was specified as counter-clockwise with respect to the design blueprints. However, AGV movement requirements are minimized if the direction of travel is clockwise. Building 405 pallets going to the shipping area and bulk transfer pallets going across the building travel shorter distances with a clockwise rotation. The only other type of pallet movements on the AGV system are bulk pallet picks going to the shipping area. For these pallets, AGV travel distances are equal with either a clockwise or a counter-clockwise rotation. Therefore, the AGV system was modeled with a clockwise direction of travel.

AGV station design is the second recommended change from the original specifications. The original design had the onload portion of the station situated before the offload portion of the station. In this design, a vehicle which offloads a pallet must leave the station area. In terms of response time to pallet movement requirements, it is better to have the offload occur before the onload in the station design. With this sequencing, an AGV which offloads a pallet can simply move over to the onload portion of the station and wait for pallets coming into the station. This change provides shorter AGV response times and better overall AGV system performance. Therefore, the AGV stations were modeled as having the offload portion of the station first and the onload portion of the station second.

C. Initial Resourcing Analysis

The first set of model results was generated to verify that the number of each resource was adequate to handle the baseline receiving workload requirements. Of the receiving resources, the number of turret trucks, VET inspectors, pallet-train receiving area forklifts, truck receiving forklifts, and AGVs were changed from the original specifications.

There were four man-up turret trucks specified in the original design. This number was increased to five based on initial resourcing results which showed extensive queueing of bin replenishment pallets in the aisle staging areas. The five turret trucks were divided into two groups. The first group consisted of three vehicles. These vehicles served the four bin replenishment aisles on the north side of the mechanized complex. The second group consisted of the other two vehicles which served the four aisles on the south side of the buildings. This division was based on the proportion of rack space in the two areas which was approximately 60 to 40 (north side to south side).

There were 12 VET inspectors specified in the original design. Again, initial resourcing results showed extensive pallet queueing in the receiving staging areas. As a result, the number of VET inpectors which were modeled was increased to 18. This increase in the number of VET inspectors was a direct result of the assumption that each pallet of a multi-pallet item must receive a VET inspection. Modeling inspections on only the first pallet of multi-pallet items results in a drastic decrease in inspector utilization from about 17 to between four and five inspectors.

The third resource altered from original specifications was pallet-train receiving area forklifts. Model verification runs showed two forklifts were adequate for the workload coming from Building 405. The original specifications called for three vehicles in this area. Pallet-train receiving area forklift resources re discussed further under the alternative scenario modeling sections below.

Truck receiving forklifts and the number of AGVs were the last two resources altered as the result of model output analysis. Because of the interaction among the number of these two resource types, a separate analysis based on an experimental design was accomplished. The results of this analysis are presented below.

D. Resource Sizing With an AGV System

Receiving forklift and AGV resource sizing was based on a second-order full factorial experimental design with two independent variables. The purpose of the experimental design was to find the relationships between the number of resources and system performance. The simulation output was used as input to a linear regression procedure which identified the significant relationships and quantified these relationships in terms of the number of receiving forklifts and the number of AGVs.

In the experimental design, the number of receiving area forklifts was varied between six and 12 and the number of AGVs was varied between eight and 12. These design endpoints were based on verification run model results. Verification run results were obtained with six receiving area forklifts and 15 AGVs. The results showed that more receiving area forklifts were needed and that 15 AGVs were significantly more than necessary.

The experimental design provided the relationships between numbers of resources and system performance factors. A total of 32 system performance factors were used. These factors measured resource utilization, queue sizes, activity times, and completion times. A subjective assessment of these system performance factors was made to come up with the resource sizing results. The assessment gave overall priority to the time to complete the daily receiving workload. The specifications call for an eight and one-half hour receiving workday. Therefore, overall priority was given to resource combinations which allowed completion within this timeframe.

The resource sizing results for the DICOMSS operation with an AGV system show nine receiving area forklifts, eight AGVs, and two pallet-train receiving area forklifts to be necessary. With this number of resources, time to complete the daily workload averages 8.4 hours. Table 2 gives the expected value of several system performance factors under baseline inputs and with the resources given above.

Table 2

SYSTEM PERFORMANCE FACTORS

Factor	Value
End of simulation	8.4 hours
Turret-truck utilization	84 percent
AGVs loaded/moving to load	55 percent
AGVs waiting/moving to wait	23 percent
AGVs loading/unloading and waiting to load/waiting to unload	22 percent

The use of eight AGVs results from a tradeoff between many performance factors. For instance, more than eight AGVs provides better response time but also results in a higher percentage of the vehicles being idle at any time. The use of at least eight is recommended based on station queueing. AGV stations have an eight pallet capacity on the on/offload belts. Less than eight AGVs results in the receiving area AGV station onload belts being filled up. As a result, forklifts could not load additional pallets onto the stations at certain times during the simulation.

The number of pallet-train receiving area forklifts required when an AGV system was modeled was either one or two. The utilization of two vehicles was between 35 and 45 percent. For one vehicle this utilization rate would be close to 100 percent. One vehicle could probably handle the workload, however, two vehicles are probably necessary when breaks are taken into account. Another reason for using two vehicles in this area is the arrival process for pallets coming from Building 405. These pallets arrive on pallet-trains (5 to 10 on each train). With only one vehicle, some of these pallets would have to wait for long periods before being transferred to the shipping area. Since these pallets must arrive for shipment with the pick-to-belt workload, timely processing is essential.

E. Resource Sizing Without an AGV System

The second scenario modeled the operation without an AGV system. In this case, forklifts handled all pallet movement requirements within the mechanized complex. An experimental design was again used to determine the mix of resources needed to accomplish the daily workload. The same number of VET inspectors and man-up turret trucks were modeled as in the first scenario.

The two independent variables in this design were the number of truck receiving area forklifts and the number of pallet-train receiving area forklifts. Truck receiving area forklifts were varied between six and 12 and pallet-train receiving area forklifts were varied between one and three.

Under this scenario, the number of pallet-train receiving area forklifts which are required remains at two. However, the utilization of these two forklifts increases slightly so that one forklift could not handle the workload.

Removal of the AGV system has two conflicting impacts on the usage of pallet-train receiving area forklifts. Workload for these forklifts is lessened because they no longer are responsible for stowing the bulk replenishment pallets transferred on the AGV system. Workload is increased because these forklifts must transfer each Building 405 pallet to the shipping area rather than simply loading them onto the AGV system. The combined effect of these two changes is a slight increase in workload for the two vehicles.

The addition of a single receiving area forklift gives system performance similar to that obtained with an AGV system. Normally, the impact of an automated system like the AGV system in the DMECSO design would be very positive. However, several factors limit the effectiveness of the DICOMSS AGV system.

The main factor limiting the AGV system effectiveness is the time it takes forklifts to interface with the system. The AGV system does not reduce the number of pallets which must be handled by forklifts. Each pallet must still get to the AGV station by forklift, be loaded onto the station by forklift, and be offloaded at the destination station by forklift. This interface time is significant when compared to the forklift travel time savings which are the main benefit of the AGV system.

A second factor limiting the AGV system effectiveness is the time difference between accomplishing a task by forklift as opposed to using the AGV system. For instance, a pallet movement from the Building 405 receiving area to the shipping area takes about 200 seconds by forklift. The same pallet movement takes about 490 seconds on the AGV system.

A final limiting factor is the travel distances of the DICOMSS pallet movement requirements. These range from 300 feet to about 1,000 feet. For these movements, the higher speed of forklifts combined with the forklift interface time required with an AGV system tend to offset AGV system benefits.

F. Input Sensitivity Analysis

1. Overview

Given the results of the resource sizing analysis, the purpose of the input sensitivity analysis was to determine how variations in workload would affect system performance. The workloads specified by DMECSO represented the expected workload during peak periods of activity (i.e., the peak receiving period at the end of the cycle). For the input sensitivity analysis, the workload was varied up and down by 25 percent of the original specifications.

Again, a second order full factorial design was used to generate results. Three replications were made at each of the 27 resulting design points. The minimum, midpoint, and maximum for each input variable are given in Table 3.

Table 3

EXPERIMENTAL DESIGN FOR THE INPUT SENSIVITITY ANALYSIS

Input Variable	Minimum	Midpoint	Maximum
Number of trucks	31	42	53
Number of bulk picks	112	150	188
Number of Building 405 pallet-trains	11	15	19

The analysis is given below in the form of a comparison and contrast of the two scenarios (with and without an AGV system). Model sensitivity to input workload is presented in terms of three types of system performance measurements. The first type are the times for completion of different receiving tasks. The second type are AGV system performance factors which pertain only to the first scenario. The final type of performance measurements are resource utilization measurements.

2. System Performance

Overall system performance is dependent on the completion times for tasks such as truck receiving, bulk picking, and bulk pallet transfers from Building 405. The basic performance measurement is time to complete all receiving functions. These completion times are given in Table 4 for both scenarios.

Table 4

TASK COMPLETION TIMES (IN HOURS)

Task	AGV System Min	AGV System Max	No AGV System Min	No AGV System Max
Trucks unloaded	5.2	9.1	5.2	9.1
Bulk picks complete	4.2	7.3	5.4	9.1
405 pallets transfered	5.7	10.2	5.6	10.3
Bin Replenishment	6.2	10.2	6.3	10.2
Bulk Replenishment	5.9	9.9	5.8	10.0
All Receiving Tasks	6.5	10.4	6.2	10.5

Expected task completion times are very similar under the two alternative scenarios. The only significant difference between the two scenarios is in the expected time of completion for bulk picks. This time is from 1.2 to 1.8 hours longer in the scenario without an AGV system. The reason for the extended time is the increased workload on the bulk picking forklift as a result of not having the AGV system. However, the increased workload is not the limiting factor in determining when all receiving functions are complete.

3. AGV System Performance

Performance of the AGV system is dependent on the number of bulk picks and the number of Building 405 pallets which must be transferred to the shipping area. Several AGV system performance results are given in Table 5.

Table 5

AGV SYSTEM PERFORMANCE RESULTS

Factor	Minumum*	Maximum*
Vehicles loaded/moving to load	2.8 veh.	5.2 veh.
Vehicles loading/unloading and waiting to load/waiting to unload	1.2 veh.	1.9 veh.
Vehicles waiting/moving to wait	0.9 veh.	4.1 veh.
Station input queue size (max)	7.6 pal.	7.9 pal.
Station output queue size	3.1 pal.	4.0 pal.
Offloads blocked (shipping station)	20	46
Offloads blocked (other stations)	0	6

* Minimum and maximum refer to the smallest and largest expected model results determined from the experimental design.

The first three factors in Table 5 represent vehicle utilization. The first two factors give the number of active vehicles. The maximum values occur when the number of bulk picks is at a maximum and the number of trucks and Building 405 pallet-trains are at a minimum. The total of these two factors is 7.1 vehicles or 89 percent of the AGV fleet. The minimum number of waiting vehicles (0.9) also occurs with these inputs and represents the other 11 percent of the AGV fleet. The minimum number of active vehicles (and correspondingly the maximum waiting vehicles) occurs when input workload includes the maximum number of pallet-trains and the minimum number of trucks and bulk picks.

The AGV system is most efficient in moving Building 405 pallets to the shipping area. The reason for this efficiency is the physical layout of the AGV system. Building 405 pallets arrive in the north corner of the building where they are transferred to the AGV system. The AGV stations in that corner of the building are very close to a vehicle wait station. Therefore, response time (time spent moving to a pallet movement requirement) is small. Also, the travel distance to the shipping area is small relative to average travel distances for bulk picks.

The second set of factors in Table 5 represent the largest AGV station input and output queue lengths. The small amount of variation implies that the amount of system workload does not have much effect on these queue sizes. The expected maximum input queue is larger than the expected maximum output queue because of the low priority given to bulk replenishment transfer pallets going from the receiving area to the other side of the building. These pallets tend to wait longer for AGVs to arrive and therefore have larger queue buildups. The average queue lengths at these stations were between two and three pallets.

The final set of factors in Table 5 represent the number of AGV offloads which were blocked at the shipping area AGV station and at all other stations. A blocked offload at the shipping area station means that a pallet arrived to offload when one vehicle was currently offloading and one vehicle was waiting to offload. Under these circumstances the blocked vehicle must circle the entire AGV track. The number of shipping station offloads blocked is a maximum when the number of bulk picks is a maximum and a minimum when the number of trucks is a maximum. However, both the minimum and maximum values (20 and 46) represent a small percentage (10 and 17 percent) of the total shipping station pallet offloads. Therefore, the difference is insignificant in terms of overall AGV system performance. The number of offloads blocked at other stations is also insignificant and does not represent a difference in system effectiveness based on input workload.

4. Resource Utilization

Resource utilization is given in Table 6. The values represent the percent of available resources which were busy (on the average) during the time the resource was active.

Table 6

RESOURCE UTILIZATION

Resource	AGV System Min	AGV System Max	No AGV System Min	No AGV System Max
Receiving forklifts	66	69	64	66
Building 405 receiving forklifts	34	46	54	55
Man-up turret trucks	78	83	80	82
VET inspectors	94	96	94	97

The only significant difference between the two alternatives is in the utilization of Building 405 receiving forklifts. The difference ranges from 20 percent at the two minimum values to 9 percent at the two maximum values.

VII. PICK-TO-BELT MODULE RESULTS AND ANALYSIS

A. Pick Size Analysis

One critical factor in achieving increased throughput is in the ability to control the distribution of cases generated for a pick cycle. This is true for both the total number of cases generated per cycle and the breakdown of these cases among the various aisles.

Essential to achieving throughput goals is the number of seavans which must be loaded each day. The workload goal for the pick-to-belt system is 40,000 cases per day with another 10,000 cases per day coming from other

bulk and nonmechanized areas. Given the facts that a seavan can hold about 36 pallets of material, an average pallet can hold 22 cases, and there are a maximum of six seavans to be packed on any one pick cycle, an average pick cycle case drop can be expected to be about 4,750 cases. It is also true that a significant portion of these cases are coming in full pallet quantities from Building 405 and bulk picks from elsewhere in the two building mechanized warehouse. This brings the expected number of cases per pick cycle down to on the order of 4,300 cases. Therefore achieving 40,000 cases per day through the pick-to-belt system may require 9 or 10 pick cycles each day. The only option in decreasing the number of pick cyles would be to increase the number of packing stations and consequently, the number of seavans packed during a given cycle.

As will be shown later in this report, variability in both pick cycle size and distribution within the aisle cause increased variability in cycle completion times. Proper control over these factors is essential to system performance.

B. Baseline Scenario Simulation Results

1. Pick Cycle Completion Times

The baseline scenario assumes belt speeds within the aisles of 80 feet per minute increased by 20 feet per minute after each merge point with a final sortation loop speed of 200 feet per minute. As discussed in the data development section, target pick rates are 450 cases per hour for walking stock selectors and 400 cases per hour for riding stock selectors. Given these pick rates, the stock selectors should generate an average of 4,300 cases per hour. All belt lengths and other system performance factors are in accordance with DMECSO specifications.

As in all scenarios tested, pick cycle sizes of 4,300, 6,450, and 8,600 cases were generated to simulate 60, 90, and 120 minutes of stock selection. These sizes were selected based upon considerations discussed above in pick cycle analysis. Each scenario was simulated three times. Table 7 shows how pick cycle completion time varies over these various cycle sizes. As can be seen from the data, considerable time is wrapped up in system flow rather than the actual picking process. The reasons for this will be discussed later in the paper.

2. Unproductive Time For Stock Selectors

For purposes of this simulation, unproductive time for stock selectors is considered to be a way of measuring overall system effectiveness. This unproductive time is defined to be the difference between the time the last case passes the scanner (a realistic estimate of when the next cycle can begin) and the time the stock selectors could have finished picking given that they experienced no delay from the system. The time the last case passed the scanner was chosen as the time to start the next cycle because it was the only reasonable spot to ensure that the integrity of cases between pick cycles was kept.

Table 7

Pick Cycle Completion Time Statistics
Baseline Scenario
(Times in Hours)

	Pick Cycle Size 4300 Cases	6450 Cases	8600 Cases
Average Value	1.52	2.20	2.81
STD	0.04	0.02	0.04
95% Conf. Interval			
Low	1.45	2.15	2.73
High	1.60	2.24	2.90

Table 8

Stock Selector Unproductive Time
Baseline Scenario
(Times in Hours)

	Pick Cycle Size 4300 Cases	6450 Cases	8600 Cases
Average Value	4.64	6.67	7.77
STD	0.36	0.24	0.50
95% Conf. Interval			
Low	3.92	6.20	6.79
High	5.36	7.13	8.74

Delays can come from several different areas. First of all, delays can result from lower level walking selectors sharing some of the capacity of their belts with cases coming from the riding selectors above. Given that no other delays occur in the system, these delays are insignificant. Other potential delays include backups at merge points ahead of the selectors which can cause belt shut downs. Depending on the severity of these queue buildups, this can be a very significant amount of time.

Lastly, delays include the time it takes the system to clear once the final case has been selected. Because of the great distances involved in this system, this delay is perhaps the most significant and the one with the least ability to be controlled. Table 8 shows the magnitude of all these delays.

3. Status of Flow Gates. Another measure of system performance is the status of the flow gates which can give a good indication of potential choke points. Table 9 gives a breakdown of the percentage of time flow gates were closed during the simulations. These data indicate significant congestion at the final sortation loop merge points which at some point in each of the simulation runs inhibited the ability of some stock selectors to function.

4. Resource Utilization. Table 10 displays resource utilization statistics for packers and forklifts/operators. These data include the time wasted waiting for the first cases to travel to the packing lanes. Even considering this fact, excess capacity clearly exists in both resource areas. By speeding the flow of material to the packing lanes, some increased resource utilization can be expected.

5. Potential Choke Points

The major choke points in the baseline scenario appear to be the merges to the main sortation loop. When congestion occurs here, the model shows gradual buildups in the trailing accumulation belts which eventually backs up to some aisles halting the stock selection process for a time. This is the major problem in the baseline design. This bottleneck prevents efficient flow to the packing stations and results in unproductive time for the packers. Clearly something needs to be done to increase the flow to the packing stations and ease congestion at the merge points.

The underlying problem can best be explained by considering the window of time each case takes to pass through a merge point. As discussed before, one hardware limitation is that the merge points and the scanner require fixed time (space) delays for cases as they pass. Obviously, since this is fixed, the space allocated for each case must be at least as big as the largest case or else jamming will occur. The scanner, according to the specifications, requires at least a distance between cases of ten inches. Accordingly, a window of three feet of belt space must be allotted to each passing case. At a speed of 200 feet per minute, each case will seize the merge point for 0.9 seconds. The specifications call for at least two cases passing the scan point every second which is an impossibility given

Table 9

Flow Gate Statistics
Baseline Scenario
(Percentage of Time Flow Gates Open)

	Stock Selection Conveyor Belt (% of Time Conveyer Belts Moving)					
Pick Size	Aisle 1	Aisle 2	Aisle 3	Aisle 4	Aisle 5	Aisle 6
4300 Cases	94.8%	86.7%	89.2%	92.6%	100.0%	97.1%
6450 Cases	86.5%	73.3%	76.7%	89.7%	100.0%	95.7%
8600 Cases	76.8%	65.4%	72.1%	85.0%	100.0%	95.2%

Note 1 : Aisle Number is Equivalent to Bay Number
Note 2 : See Figure 2 for Corresponding Aisle Number

	Sortation Belt / Flow Monitor (% of Time Sortation Belt Gate Open)					
Pick Size	Gate 1	Gate 2	Gate 3	Gate 4	Gate 5	Gate 6
4300 Cases	77.5%	83.3%	95.3%	60.9%	100.0%	56.0%
6450 Cases	76.8%	76.9%	91.3%	53.7%	100.0%	45.1%
8600 Cases	76.1%	77.0%	90.1%	53.2%	100.0%	43.3%

Note 3: See Figure 3 for Corresponding Sortation Belt Flow Gates

Table 10

Resource Utilization Statistics
Baseline Scenario
(% of Cycle Time Busy)

	Packer Utilization 4300 Cases	6450 Cases	8600 Cases
Average Value	58.1%	60.7%	63.0%
STD	1.4%	0.8%	1.1%
95% Conf. Interval			
Low	55.3%	59.0%	60.8%
High	61.0%	62.3%	65.2%

	Forklift Utilization 4300 Cases	6450 Cases	8600 Cases
Average Value	24.8%	24.8%	25.6%
STD	0.4%	0.2%	0.6%
95% Conf. Interval			
Low	24.0%	24.4%	24.9%
High	25.5%	25.2%	26.9%

the belt speed and the space required per case. In order to meet the standard of two cases each second, the final sortation belt would have to travel at 360 feet per minute. Even if the belt could physically move that fast, it is doubtful that the diverters to the packing stations could function properly at that speed.

C. Effects of Deviations in Workload Among Aisles

1. Types of Workload Deviation Modeled

The Seavan Planner, which in the current system generates pick batches, is intended to be utilized in the proposed DMECSO design. In its current form, batches of picks are released based upon cube and weight constraints. No attempt is made by the Seavan Planner to balance workload among differing aisles. For this reason, deviation in workload among aisles was tested in the pick-to-belt module.

As previously mentioned, the number of locations (pick facings) varied by aisle. Two of the four high bay areas had one third of their capacity deleted to allow for accumulation and sortation belt space. Therefore, scenarios were modeled which varied the number of picks on an aisle by the number of available locations to pick from.

2. Effects on Individual Stock Selectors

Some interesting dynamics were observed when the distribution of picks were varied by aisle. Stock selectors with more picks during a cycle tended to have some improved productivity. This was true because the more workload in an aisle, the denser the picks at a facing and the closer the distance to the next active facing. Since the actual time to pick once at a facing was relatively small compared to travel time, and travel time to the next location was shorter, the selector became more productive. Conversely, stock selectors with fewer picks during a given cycle tended to spend more time traveling and less time at the actual pick facing which caused them to appear less productive. This effect will, no doubt, be experienced in the real system and not just in the model.

For the above reason, it was possible for stock selector unproductive time to actually decrease somewhat under certain small variations in workload. However, the larger the variations in workload and the larger the size of the pick cycle, the more pronounced the effects of the deviation. Changes to the distribution of workload among the aisles tended to drastically effect the minimum amount of time required for the stock selectors to complete their pick cycles given that no other system bottlenecks occurred.

3. System Performance

Tables 11, 12, and 13 quantify the effects on pick cycle completion times, stock selector unproductive times, and resource utilization for the scenarios tested. Unfortunately, the excessive congestion experienced at merge points tends to mask the magnitude of the effects of the deviation in

Table 11

Pick Cycle Completion Times
Workload Deviation Scenarios
With 95% Confidence Interval Statistics
(Times in Hours)

	Weighted By Aisle 4300 Cases	Weighted By Aisle 6450 Cases	Weighted By Aisle 8600 Cases	*	Weighted By Number of Pick Facings 4300 Cases	Weighted By Number of Pick Facings 6450 Cases	Weighted By Number of Pick Facings 8600 Cases
No Deviation							
Mean	1.52	2.20	2.81	*	1.58	2.15	2.81
STD	0.04	0.02	0.04	*	0.01	0.03	0.02
Conf Int -Low	1.45	2.15	2.73	*	1.56	2.09	2.77
-High	1.60	2.25	2.90	*	1.60	2.21	2.86
10% Deviation							
Mean	1.49	2.20	2.82	*	1.58	2.18	2.88
STD	0.06	0.05	0.01	*	0.03	0.09	0.05
Conf Int -Low	1.38	2.11	2.81	*	1.52	2.00	2.79
-High	1.60	2.29	2.83	*	1.65	2.37	2.98
50% Deviation							
Mean	1.65	2.44	3.14	*	1.73	2.40	3.11
STD	0.08	0.05	0.06	*	0.07	0.13	0.08
Conf Int -Low	1.49	2.34	3.01	*	1.60	2.16	2.94
-High	1.81	2.54	3.26	*	1.85	2.65	3.27

Table 12

Aggregate Stock Selector Unproductive Time
Workload Deviation Scenarios
With 95% Confidence Interval Statistics
(Times in Hours)

	Weighted By Aisle 4300 Cases	Weighted By Aisle 6450 Cases	Weighted By Aisle 8600 Cases	*	Weighted By Number of Pick Facings 4300 Cases	Weighted By Number of Pick Facings 6450 Cases	Weighted By Number of Pick Facings 8600 Cases
No Deviation							
Mean	4.64	6.67	7.77	*	5.33	6.50	8.62
STD	0.37	0.24	0.50	*	0.15	0.31	0.18
Conf Int -Low	3.92	6.20	6.79	*	5.02	5.88	8.27
-High	5.36	7.13	8.74	*	5.63	7.11	8.96
10% Deviation							
Mean	4.42	6.61	7.92	*	5.31	6.88	9.30
STD	0.53	0.54	0.09	*	0.25	0.91	0.51
Conf Int -Low	3.37	5.54	7.75	*	4.82	5.09	8.30
-High	5.46	7.68	8.10	*	5.80	8.67	10.29
50% Deviation							
Mean	5.98	9.09	11.43	*	6.74	9.26	11.99
STD	0.87	0.59	0.75	*	0.70	1.22	1.16
Conf Int -Low	4.27	7.94	9.94	*	5.37	6.86	9.70
-High	7.68	10.24	12.91	*	8.12	11.66	14.27

Note 1 : Unproductive time statistics are for all ten Stock Selectors

Table 13

Resource Utilization
Workload Deviation Scenarios
(Times in Seconds)

Packers

	Weighted By Aisle 4300 Cases	Weighted By Aisle 6450 Cases	Weighted By Aisle 8600 Cases	Weighted By Number of Pick Facings 4300 Cases	Weighted By Number of Pick Facings 6450 Cases	Weighted By Number of Pick Facings 8600 Cases
No Deviation						
Mean	58.1%	60.7%	63.0%	56.0%	62.0%	63.0%
STD	1.4%	0.8%	1.1%	0.4%	1.0%	0.6%
10% Deviation						
Mean	59.3%	60.3%	62.8%	55.8%	60.5%	62.0%
STD	2.3%	1.1%	0.2%	1.1%	2.0%	0.7%
50% Deviation						
Mean	53.6%	54.5%	56.6%	51.2%	55.5%	57.1%
STD	2.5%	0.9%	0.9%	2.0%	3.0%	1.6%

Forklifts

	Weighted By Aisle 4300 Cases	Weighted By Aisle 6450 Cases	Weighted By Aisle 8600 Cases	Weighted By Number of Pick Facings 4300 Cases	Weighted By Number of Pick Facings 6450 Cases	Weighted By Number of Pick Facings 8600 Cases
No Deviation						
Mean	24.8%	24.8%	25.6%	23.8%	25.4%	25.5%
STD	0.4%	0.2%	0.6%	0.3%	0.4%	0.3%
10% Deviation						
Mean	25.0%	25.0%	25.4%	23.8%	25.1%	25.0%
STD	0.9%	0.8%	0.1%	0.4%	0.9%	0.4%
50% Deviation						
Mean	22.9%	22.5%	23.0%	21.8%	22.9%	23.1%
STD	1.0%	0.3%	0.3%	0.8%	1.3%	0.6%

aisle workload in terms of cycle completion time. The implication of this is that the time of last selection becomes unimportant when the case will have to wait in line anyway. If queueing were not a significant problem, this workload deviation would be a substantial system performance drain. As an example, differences in best case (no other system bottlenecks) stock selector completion times of over 1.4 hours were observed in the 50 percent deviation scenario for a pick cycle of 8,600 cases. While in some individual simulation runs slight deviations in workload caused the system to run more efficiently, the variation in completion times experienced in the model appear significant especially in larger pick cycles.

D. Effects of Speeding the Sortation Belt

1. Overview. Based upon data shown in an interim project briefing, DMECSO requested that the model be tested with a faster sortation belt. In this scenario, the sortation belt speed was increased from 200 to 285 feet per minute. This was done to help alleviate congestion at the merge points and to speed the flow of material to the packing stations. Since excess capacity existed in the packing area, this appeared to be a logical enhancement to the design. One major concern with this enhancement was the ability of the diverters to the packing lanes to handle the increased speed. For modeling purposes, it was assumed that the diverters could keep up with the increased sortation belt speed. It was also assumed that the three foot window of space seized by a case on the sortation belt would not need to be increased for the scanner to function properly at the faster speed.

2. System Performance. Tables 14, 15, and 16 detail the effects on cycle time, stock selector unproductive time, and resource utilization for this scenario. Vast improvements were experienced in overall system performance. Packer capacity was exceeded somewhat at different points in the model causing cases to balk from the packing lanes and circle around the sortation belt. This balking effect is not necessarily bad from a system standpoint because it ensures that packers are more fully utilized. Provided this balking is not extreme, as the simulation runs indicate, it should not be a detriment to system performance.

E. Effects of Adding a Second Sortation Belt

1. Overview. Because of the excessive queueing problems associated with the baseline scenario merge points, a scenario which added a second sortation belt was modeled. Under this new scenario, the number of merge points was decreased and the flow of material to the packing stations was significantly increased. The model merged accumulation belts A and C into one sortation loop and accumulation belts B and D on a second sortation belt.

Table 14

Pick Cycle Completion Time Statistics
Sortation Belt Speed 285 Ft/Min
(Times in Hours)

	4300 Cases	6450 Cases	8600 Cases
Average Value	1.39	1.71	2.20
STD	0.03	0.04	0.02
95% Conf. Interval			
Low	1.32	1.63	2.16
High	1.45	1.78	2.24

Table 15

Aggregate Stock Selector Unproductive Time
Sortation Belt Speed 285 Ft/Min
(Times in Hours)

	4300 Cases	6450 Cases	8600 Cases
Average Aggregate Value	4.00	4.04	4.88
STD	0.32	0.35	0.10
95% Conf. Interval			
Low	3.37	3.35	4.68
High	4.64	4.73	5.08

Table 16

Resource Utilization Statistics
Sortation Belt Speed 285 Ft/Min

Packers

	4300 Cases	6450 Cases	8600 Cases
Average Value	63.8%	77.9%	80.8%
STD	1.3%	1.7%	0.8%
95% Conf. Interval			
Low	61.2%	74.4%	79.2%
High	66.4%	81.3%	82.3%

Forklifts

	4300 Cases	6450 Cases	8600 Cases
Average Value	27.0%	32.3%	33.0%
STD	0.6%	1.0%	0.3%
95% Conf. Interval			
Low	25.9%	30.3%	32.5%
High	28.2%	34.3%	33.6%

2. System Performance

Improvements in system performance were impressive. As in the previous scenario with a faster belt speed for the sortation loop, balking occurred at the packing lanes which helped ensure increased utilization of resources. Unlike the previous scenarios, the need for a flow monitor was eliminated because very little queueing occurred at merge points, and accumulation belts never exceeded their capacities. Specific system performance data are shown in Tables 17, 18, and 19.

This two belt scenario also added a very important benefit in that it allowed redundancy in the critical choke point area. A sortation belt malfunction in the previous scenarios implied complete system shut down until the problem was corrected. A second sortation belt allows the system to continue functioning, although at a slower pace, and could significantly reduce the consequences of such a failure. A second sortation belt would eliminate the problems associated with the increased speed on diverters and scanners mentioned in the previous section.

Two concerns were raised with the practicality of adding a second sortation belt. Physical space is at a premium in the sortation and packing area. Some questions exist as to whether or not there is enough room for a second belt. The other concern raised was the cost associated with an additional belt.

F. Significance of Riding Stock Selector's Pick Direction

Even when the final sortation belt speed was increased or an additional sortation belt was added to the system, some unproductive time was still observed. This was largely due to the time it took the last case selected to traverse the system such that a new pick cycle could begin. The DMECSO design called for the riding selectors to serpentine through their respective aisles beginning on the end of the aisle closest to the spiral, picking to the opposite end of the aisle, raising a level and picking back toward the spiral, raising to the highest level, and ending at the end of the aisle farthest from the spiral down (see Figure 2). This implied that the last case picked could potentially have to travel 400 seconds before reaching the spiral down to the lower level belt. The model was run testing the effects of reversing the riding selectors path such that the final case selected would be closest to the down spiral.

While the reversed path changed the dynamics of the queueing, both the increased belt speed model runs and the added sortation belt model runs showed some improvements. A major assumption in this area is that the workload within each level is balanced and the riding selector must completely traverse all levels within his aisle to finish his selections.

Table 17

Pick Cycle Completion Time Statistics
Two Sortation Belts
(Times in Hours)

	4300 Cases	6450 Cases	8600 Cases
Average Value	1.40	1.70	2.04
STD	0.02	0.01	.00
95% Conf. Interval			
Low	1.35	1.68	2.03
High	1.45	1.72	2.05

Table 18

Aggregate Stock Selector Unproductive Time
Two Sortation Belts
(Times in Hours)

	4300 Cases	6450 Cases	8600 Cases
Average Value	4.12	4.02	4.16
STD	0.26	0.09	0.07
95% Conf. Interval			
Low	3.61	3.83	4.02
High	4.63	4.20	4.30

Table 19

Resource Utilization Statistics
Two Sortation Belts

Packers

	4300 Cases	6450 Cases	8600 Cases
Average Value	63.4%	78.2%	87.1%
STD	1.3%	0.6%	0.2%
95% Conf. Interval			
Low	60.8%	77.0%	86.7%
High	66.0%	79.4%	87.4%

Forklifts

	4300 Cases	6450 Cases	8600 Cases
Average Value	27.3%	32.4%	35.4%
STD	0.6%	0.2%	0.3%
95% Conf. Interval			
Low	26.0%	31.9%	34.9%
High	28.6%	32.9%	35.9%

G. Insights

Clearly some improvements can be made to the baseline design. The key to optimizing throughput is keeping the packers busy and the results of the baseline scenario runs indicate excess capacity for both packers and shipping area forklifts. At the same time, simulation results indicate that the stock selectors are able to pick at a faster rate than the packers can handle. This inconsistency is due to the inefficiencies in the conveyor belt system, specifically in the excessive amount of time spent in the merging of various belts.

The above problem appears to be a material flow problem. The packing stations are able to handle a faster rate of flow and the stock selectors are already picking at a faster rate. Two ways to alleviate this problem were simulated and both appear to be potential solutions. Increasing the speed of the sortation loop is a quick fix provided the system hardware can handle the associated workload. Adding a second sortation belt is perhaps a better solution in that it not only increases the flow of material to the packing station but also allows some important redundancy to the system and potentially lessens the negative effects of mechanical problems on one sortation belt. Also, if one sortation belt speed can be increased, then the second belt speed could be increased as well providing more system flexibility.

One other limiting factor in system throughput is the number of packing stations. As mentioned earlier in the analysis, six packing stations imply an average case drop of about 4,700. A significant portion of these cases are not coming from the pick-to-belt system but from full pallet picks and nonmechanized picks from Building 405. Simulation results also indicate some efficiency increases associated with longer pick cycles in that stock selectors spend less time traveling and more time at the actual pick facing. The net effect is that six packing stations forces more pick cycles of shorter size which may not be optimal for the system. More packing stations could increase throughput potential and add some important redundancy to the system. Further simulation in this area may be warranted.

Finally, critical to overall system control is the ability of the Seavan Planner to control the workload of each pick cycle. This implies that the material is stored in such a fashion that it is possible to balance the workload among the aisles. Both the storage aspect and the balancing aspect are not presently supported by the Seavan Planner yet are critical assumptions to system performance.

VIII. CONCLUSIONS AND RECOMMENDATIONS

The high costs and limited benefits of the proposed AGV system indicate that it should be reconsidered. The AGV system does not eliminate the need for forklifts as previously suspected but merely redefines their role and increases the number of times they must handle material. Total time to stow a receipt actually increases with an AGV system due to the amount of time associated with getting the pallet to the appropriate AGV station, loading, keying in a destination, traveling to the next station, offloading, and traveling by forklift to the ultimate destination. The AGV system is not only costly and inefficient but also takes up a great deal of scarce floor space which might better be used for storage aids.

Simulation results also indicate that a realignment of certain resources is necessary to achieve anticipated receiving throughput requirements. Ten forklifts are needed in the receiving area (assuming no AGV system). An additional man-up turret truck will be required to complete the workload in a one shift receiving operation. A total of 18 VET inspectors will be needed to handle expected receipt workload.

In the pick-to-belt area some marked improvements can be made to enhance system performance. First and foremost, the flow of material to the packing stations should be increased to take advantage of the excess capacity and alleviate congestion at merge points. This can be accomplished by either speeding the sortation belt or adding a second one. Adding a second sortation belt seems to be the more flexible solution and a better way to relieve congestion and adds redundancy to the design in the most critical choke point area.

Some consideration should be given to adding packing stations as a method of improving throughput. More packing stations imply fewer pick cycles of larger sizes and, consequently, a more efficient stock selection process. Additional simulation in this area may be warranted provided that there is sufficient space for additional lanes.

Balanced workload is critical to system performance. Given that bottlenecks at the sortation loop are alleviated by one of the above recommendations, the next major potential system inefficiency is the difference in stock selection completion times caused by unbalanced workload. Significant changes will have to be made to the current form of the seavan planning function in order to accommodate this requirement.

The following items are specific recommendations based upon simulation results:

1. Recommend that the AGV system be eliminated from the design and that an extra forklift be added to the receiving area to handle the associated increase in workload.

2. In the event that the AGV system is kept in the design, recommend that:

a. Direction of AGV path be reversed to clockwise.

b. Onload and offload belts at each station be reversed to offload first and onload second.

c. A queueing potential of at least one AGV per station be incorporated in the design.

d. An offload station is not necessary at the truck area receiving station.

e. Eight vehicles can handle the expected workload rather than the 15 originally planned.

3. Recommend nine forklifts in the receiving area (assuming no AGV system.

4. Recommend two forklifts in the Building 405 receiving area for bulk picks.

5. Recommend a total of five man-up turret trucks as opposed to four in the original design.

6. A total of 18 VET inspectors will be required to handle the anticipated workload.

7. Add a second sortation belt to alleviate congestion problems at the merge points.

8. In the event that adding a second sortation belt is not feasible, recommend that the speed of the final sortation belt be increased to allow for increased flow of material to the packing stations (assuming no corresponding increase to the window of belt required per package).

9. The Seavan Planner should be enhanced to provide for balanced workload among the aisles. Included in this recommendation is that material should be stored in such a fashion as to allow for balanced workload.

10. Recommend further study into the feasibility of adding packing lanes to the system to allow for increased pick cycle sizes and increased system flexibility and performance.

11. The picking direction of the riding stock selectors should be reversed to limit overhead time in the system due to the increased travel time of the final cases picked.

12. Recommend transferring two of the forklifts from the packing area to the receiving area.

13. Recommend bringing the pallet-trains from Building 405 directly to the shipping area without using the AGV system.

APPENDIX B

DEFENSE LOGISTICS AGENCY
DEPOT MECHANIZATION SUPPORT OFFICE
C/O DEFENSE GENERAL SUPPLY CENTER
Richmond, Virginia 23297-5000

IN REPLY REFER TO DMECSO 30 May 1986

SUBJECT: DICOMSS Simulation Data Request

TO: DORO

1. Reference your letter, 28 May 86, subject as above.

2. The following answers are provided:

a. Receiving:

(1) Number of trucks per day - 50 avg, min 5-max 60.

(2) Number of pallets per truck - Avg 16-20.

(3) Hours of receiving operation and distribution of truck arrival times - 0630-1500, trucks arrive by appointment - assume 7 trucks/hour max. - last 5-7 days of cycle.

(4) Number of pallets which are destined for Bldg 405 - Approximately 150 per day.

(5) Number of forklifts in receiving area - 5 or 6 (506/507 only).

(6) Number of receiving doors used concurrently - Up to 14.

(7) Capacity (in pallets) of receiving area - Staging only up to 250 pallets.

(8) Time for a forklift to unload a pallet - Avg. 30 to 60 seconds (506/507) - 1-1/2 to 2 minutes (405).

(9) Time for inspection (detrash, verify count, vet inspect) - detrash not considered - verify/inspect - 4.2 minutes/receipt.

(10) Percent of time a pallet must be remade - Estimated about 20% of pallets received must be remade, includes slip sheeted material, plus the material from rail cars that must be palletized. Time average 3 min/pallet.

(11) Who performs inspection functions - DWASP procedures - DLA warehouseman. VET procedures - US Army Vet Service.

(12) Percentage of receipts which go directly to packing - None.

(13) Percentage of receipts that will go directly to Bldg 405 - 5-10%.

(14) Percentage of receipts which go directly to bulk locations in Bldgs 506/507 - 15%.

(15) Percentage of receipts which go directly to pick to belt modules - 60%.

Percentage of receipts that will be split between pick to belt and bulk locations - 15%.

(16) Number of pallets per day from Bldg 405 to include arrival process - Avg. 100 per day - arrive 5-10 at a time to palletizing area.

b. Pick to Belt Modules.

(1) Belt speeds.

(a) Point of entry of carton, i.e., floor or mezzanine area - 70/80 ft/min.

(b) After merge add 20 ft/min (at each consecutive merge).

(c) Sort loop 160-200 ft/min.

(d) Two scans/sec required to meet throughput.

(2) Speed of pick carts - vertical speed - 70/100 ft/min.
horizontal speed - 275-350 ft/min.

(3) Pick rates of pick cart selectors and walking selectors - pick cart selectors - 400 cartons/hr - walking selectors - 450 cartons/hr.

(4) Distribution of case lengths - range - 0.05 CF to 5.5 CF & 2 to 75 lbs. - lengths - min-3 inches, max-2.5 ft, avg-18 inches.

(5) Number of picks at a location (by location type) - Cannot give a good answer. However, will pick up to six customers at each pick face - number of cartons will vary.

(6) Hours of picking operations - 0630-1530, longer if necessary.

c. Bulk Area Picking:

(1) Number of pallets per day - 250, includes Bldg 405.

(2) Time for forklift to pick a pallet:

Start, - driver has pick ticket or bar code.
Operations - drive to pallet, get off forklift, apply bar code, wand bar code, get on lift, lift load - 1.1 minutes.
End, start towards destination.

d. Packing (Palletizing) Stations:

(1) Time to pick from loop conveyors - palletizers will handle 500-600 cartons per hour (each person) will be 2 per loop conveyor.

(2) Time to stretch wrap a pallet - Index - wrap - movement - 1 minute.

(3) Forklift speed in palletizing area - max. 5 mph - avg 3-3.5 mph.

(4) Number of forklifts in palletizing area - Total 10- handles all. Shipping, i.e., loading of vans.

(5) Time to load a pallet into a SeaVan and time a pallet is staged prior to loading into SeaVan. - 45 seconds, staging - max. 1-1/2 hours.

(6) Bar code read rate - 99% ok, approximately 50 cartons refused per 50,000 scanned.

(7) Length of Placement of Accumulation Belts - DMECSO will point these out on planning boards.

(8) Time to rekey or manually sort no scans - 3 to 4 seconds each - estimate up to 1/2 hour total to handle all new direct, i.e., either no read or a full ~~5 per~~ spur "go around."

(9) Number of cases per pallet - max. CF 60, Avg CF 46 - range 8-40 cases/pallet, 2 vary as you want.

(10) Number of pallets sent to Bldg 405 for shipment - Approx. 30-40 day.

e. Automated Guided Vehicles (AGV):

(1) Anticipated speed of AGV - 240 ft/min.

(2) Directional capabilities of AGV - on line-forward only - off line-forward and reverse under manual control.

(3) Number of AGV's - 15.

(4) Maintenance Schedule - All preventive maintenance will be accomplished off shift.

(5) Capacity (in pallets) of AGV - 1 each.

(6) Load/unload time at AGV stations - 1 min.

(7) Capacity of each AGV station - inbound/outbound - two separate lines.

(8) Time for forklift to unload/load pallet - 20 seconds.

(9) Key in time to call/route AGV - 10 seconds.

(10) Can onload and offload occur at the same station at the same time - Yes.

(11) What is maximum number of AGV's at each station - two.

f. Other Critical Areas:

(1) Number of replenishment actions per day within Bldg 506/507 - does not need to be considered.

(2) Number of picks/day, i.e, case picks of non-conveyables - data in bulk already.

(3) Are there dedicated receiving vehicles (i.e, walkie riders) number - No-only forklifts in receiving. We may add walkie riders later.

(4) Number of forklifts:

(a) Swing reach man-up narrow aisles - 4 each in stow-electric, 4000 lb.

(b) Receiving sit down electric 4000 lbs.

(c) Shipping - 6 each sit down electric 4000 lbs.
10 each sit down electric 4000 lbs.

(d) Bldg 405 - 10 each electric 4000 lbs.

(e) One tractor with 6 trailers for non-conveyable picks.

2. If there are any comments or further questions, please contact LTC Rivers or Ms. Jan Sjostrom, AV 695-4032.

3. Please advise by telephone when simulation results will be available.

TRWild
T. R. WILD
Captain, SC, U. S. Navy
Chief, DLA Depot Mechanization
Support Office

END

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